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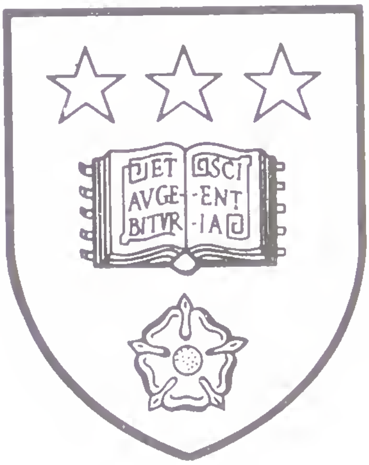

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A STUDY IN TACTILE SPHYGMOLOGY.

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HENRI FOUQUET.

From an oil-painting at the Faculty of Medicine of Montpellier.

"Desine . . . . novitate exterritus ipsâ,
Expuere ex animo rationem; sed magis acri
Judicio perpende."

T. Lucr. Car. *de rer. natur.* Lib. ii.
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HEART STUDIES,
CHIEFLY CLINICAL.

I.

THE PULSE-SENSATIONS:

A STUDY IN TACTILE SPHYGMOLOGY.

BY

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IN MEDICINE AT THE ROYAL COLLEGE OF PHYSICIANS
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PREFACE.

The contrast between the mechanical accuracy and elaborate detail of the sphygmogram, and the vague and inconclusive character of the pulse impressions hitherto gained by palpation, is sufficient to explain, though it hardly justifies, the relative neglect of a valuable clinical method. Instead of being made to share in the general advance, palpation of the pulse has been almost ignored in modern investigations. Indeed, this obvious disproportion in the amount of attention bestowed on the instrumental to the exclusion of the digital method, was the sign which told of something left undone, and which pointed to the tactile pulse phenomena as to a mine to be explored.

It might seem almost superfluous to dwell upon the essentially clinical nature of this investigation. Every digital examination of the pulse is, in its procedure, clinical. But this character belongs in a more special sense to the present inquiry, since its original idea and its ultimate object have been to widen the clinical scope of pulse observations, by rendering the tactile pulse available for the more accurate study of disease. It is necessary, however, to explain why the results which are now to be submitted, should comprise only those which may be claimed as part of the sphere of physiology.

In the endeavour to bring the tactile method "up to date," and to compare and, if possible, harmonize its indications with the sphygmographic data, in connection with the various morbid pulses, the *normal tactile pulse* called for the first and, at the same time, for the most searching scrutiny. A large proportion of these pages had thus to be devoted to a study of the latest advances made in instrumental sphygmology, and of the works of Marey, Fick, von Kries, von Frey, Roy and Adami, Ozanam and others.

As to the author's special observations and practical results, for which his responsibility is undivided, they are put forward as containing the germ of a practical method which, by reason of its simplicity, should develop into one of general clinical utility. Even the practitioner of medicine, debarred from using the sphygmograph, might, with its help, not only add greater value and interest to his everyday pulse observations, but gain ready access to fresh avenues of research. Crude and unfinished as the method still remains at this stage, to have longer withheld it from so many hands capable of improving it and of working out its clinical applications, until some adequate show of results had slowly accrued from the author's unassisted labour, would have served rather the literary credit of his performance than the best interests of clinical medicine.

Even should these hopes of clinical usefulness prove delusive, some good service may yet have been done by the comparative study, undertaken in Part IV., of the work and theories of eminent authorities. To each of them, and to their publishers, grateful acknowledgment is due for the ample references which they have sanctioned; but towards Professor von Kries and Professor von Frey the obligation incurred is specially great.

In the arrangement of these pages the chief care has been to provide facilities for the reader, even at the expense of some repetition, and to multiply headings and diagrams for the better elucidation of new facts and ideas. The concluding summary of the results obtained may be of service to those lacking time for a study of the theory of the pulse, whilst it places in a clear light the distinction between mere inferences and facts.

The author is indebted to his nephews, Mr. E. Billecocq and Mr. P. de Vaumas, for their valuable assistance in the preparation of some of the drawings, and to Messrs. Fargues for much care and success in their reproduction. He also records with special pleasure his obligation to Mr. Springer, of Berlin, for his courtesy in connection with the illustrations reproduced from Professor von Frey's "Die Untersuchung des Pulses."

W. E.

33 CURZON STREET,
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INTRODUCTION.

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TACTILE SPHYGMOLOGY AND INSTRUMENTAL SPHYGMOLOGY.

A RETROSPECT.

Tactile Sphygmology, probably the most ancient among the branches of medical science, is now far behind some of its younger sisters.

What is the pulse? Is it round or oval? Does the artery expand or not at each beat? These are some of the problems which, without levity and without despair, we are still discussing at this end of the nineteenth century.

Instrumental Sphygmology—i.e., *Sphygmography*, after claiming for nearly half a century the almost undivided attention of students of the pulse, and supplying valuable fragments of information, cannot yet answer some of the more simple questions connected with the pulse-wave.

The great want seems to have been a systematic co-operation between the two methods, hardly attainable so long as a special study of the *Pulse-Sensations* was neglected. To this we should now turn, in the hope that, having learnt much from the sphygmograph that has led to a better understanding of the tactile pulse, we may likewise, after puzzling in vain over the sphygmogram, find help in the simpler method.

I.

BEFORE THE SPHYGMOGRAPH.

It may be doubted whether unaided tactile investigation could ever have unravelled the mystery of the pulse, without the help of the sphygmograph; so difficult is it to concentrate sufficient attention on the sensations of the finger.

Concerning tactile analysis of the pulse few writers have anything to say. Galen's unrivalled industry led him some part of the way in this direction. For instance, he knew so well how to recognise the pulse-wave in the intervals between the beats, that he warns younger students not to take notice of this phase of the pulse. "Moreover, I think that beginners should practise themselves as though the systole could not be felt." * And elsewhere he expressly describes a "pause in systole" (by systole meaning the period of contracted or reduced volume of the pulse). But these accurate observations of fact did not survive as long as some of his errors.

We have no reason to imagine, and it is in itself unlikely, that Galen's analytical knowledge of the pulse had ever been surpassed or even equalled by physicians in a more remote antiquity. After him, it cannot even be said that sphygmology remained at

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* Ad Tirones, cap. iii.

a standstill. Some of the old ground was lost; and in spite of collateral advances in science, no fresh ground was won in the direction of pulse-analysis, down to the time of Fouquet. Even Harvey's discovery made remarkably little impression on the progress of sphygmology.

The following lines by Sir John Floyer,* written in an age of comparative enlightenment, long after the experimental method had been applied by Harvey to the circulation, are a striking instance, among many earlier ones, of failure of the best intentions in this direction.

> "We were taught by Galen 'That we must admit nothing relating to the Pulse but what we evidently feel; but I cannot but believe his Fancy imposed on him when he asserts, that he felt the contraction of the Artery, which he endeavour'd to prove, because the Artery makes an Impression in the Pulp of the Fingers, and he thought he felt the receeding of the Artery from that Impression; but it is plain that we can discern no more in a natural Pulsation than the Stroke given to the Finger, and the interval betwixt each stroke by the numbering of the Pulse in a minute, whereby we discern when the Intervals are longer or shorter. The distinction of two Intervals was too curious, and not useful. The interior quiet betwixt the contraction and distention of the Artery is sensible, but the exterior betwixt the distention and contraction is insensible; and 'tis allowed that we cannot discern the beginning of the distention nor the end of the contraction, 'tis enough to consider the Intervals betwixt the Pulsations.'"

To fail to observe new facts is a misfortune with which we are all more or less familiar. To refuse to notice old facts, pointed out by the greatest observers, is something worse. We should feel less sympathy with Floyer's mistake in rejecting Galen's testimony and in failing, in spite of that testimony, to recognise the living facts enacted under his own fingers many hundred times each day, had this our own time been free from the same reproach.

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* "The Physician's Pulse-Watch; or, an Essay to Explain the Old Art of Feeling the Pulse; and to Improve it by the Help of a Pulse-Watch." By Sir John Floyer, Knight. London: Printed for Sam. Smith and Benj. Walford, at the Prince's Arms in St. Paul's-Church-Yard, 1707 (p. 6.)

The Limitations of the Sense of Touch.

The strange fact that for thousands of years the self-same things, now familiar to us, were under the touch of sensitive fingers, yet not felt, is probably best explained in connection with the natural limitations of the sense of touch,* and with its supreme conceit. The sense of sight, its superior in accuracy and in activity, deprives it of much of its employment. Except by the blind, and in some of the arts, it is rarely used for analytical purposes. For scientific work the sense of touch wants a special education ; and we need to be told even more what to feel, than what to see.

Anatomy and Physiology are our real teachers of clinical sphygmology. Its evolution has been delayed until the dawn of clearer notions concerning heart, artery, and pulse-wave. In a word, pulse-analysis belongs less to art and more to science—it is less a matter of intuition, and more a matter of instruction, than has been generally supposed.

Struthius and Fouquet.—The Graphic Method in Connection with the Tactile Pulse.

Had we inherited, from the great teachers of the past, drawings of the things felt by them, as well as

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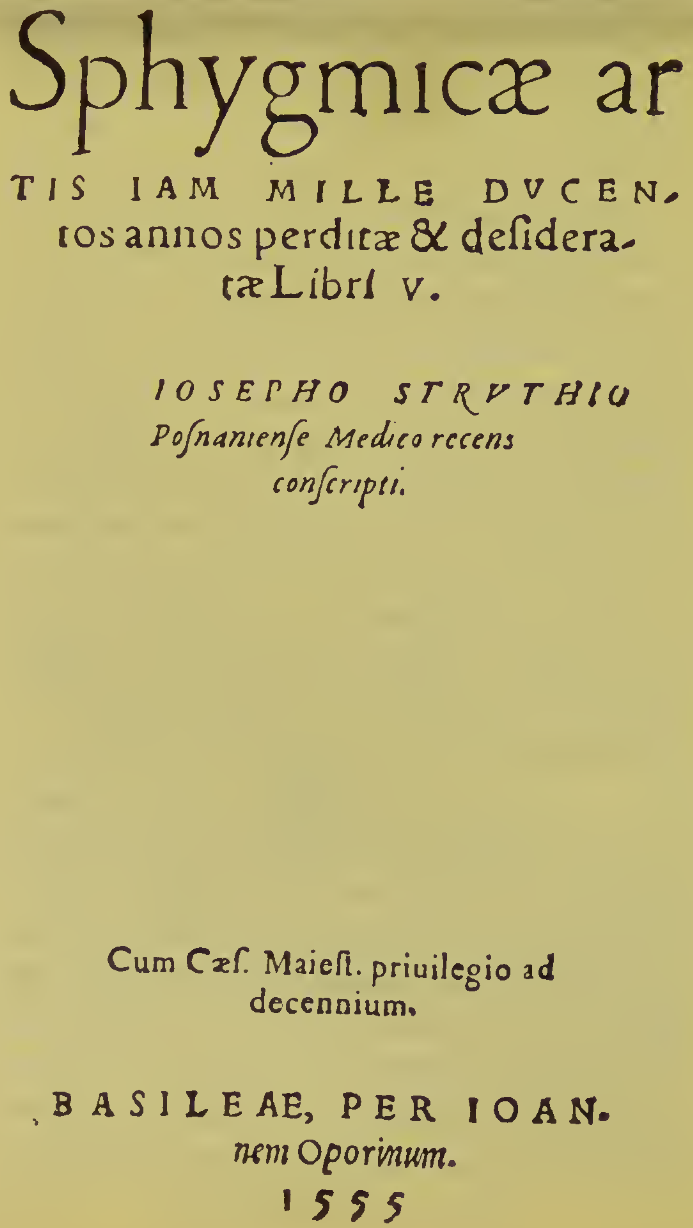
* *Cf.* p. 13 ; and chap. iii. p. 70.

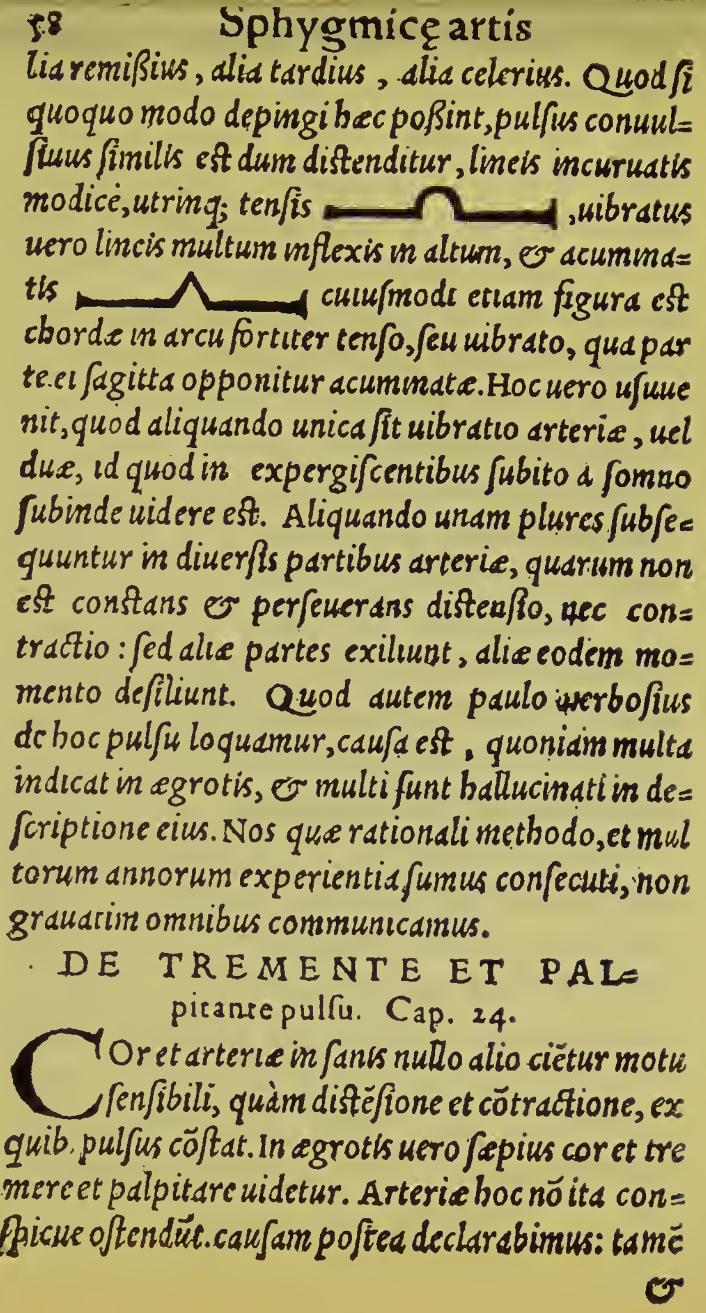


Sphygmicæ ar
TIS IAM MILLE DVCENtos annos perditæ & deſideratæ Libri V.

IOSEPHO STRVTHIO
Poſnanienſe Medico recens
conſcripti.

Cum Cæſ. Maieſt. priuilegio ad
decennium.

BASILEAE, PER IOANnem Oporinum.
1555



lia remiſſius, alia tardius, alia celerius. Quod ſi quoquo modo depingi hæc poſſint, pulſus conuulſiuus ſimilis eſt dum diſtenditur, lineis incuruatis modicè, utrinq; tenſis , uibratus uero lineis multum inflexis in altum, & acuminatis cuiuſmodi etiam figura eſt chordæ in arcu fortiter tenſo, ſeu uibrato, qua parte ei ſagitta opponitur acuminatæ. Hoc uero uſuuenit, quod aliquando unica ſit uibratio arteriæ, uel duæ, id quod in expergiſcentibus ſubito à ſomno ſubinde uidere eſt. Aliquando unam plures ſubſequuntur in diuerſis partibus arteriæ, quarum non eſt conſtans & perſeuerans diſtenſio, nec contractio: ſed aliæ partes exiliunt, aliæ eodem momento deſiliunt. Quod autem paulo uerboſius de hoc pulſu loquamur, cauſa eſt, quoniam multa indicat in ægrotis, & multi ſunt hallucinati in deſcriptione eius. Nos quæ rationali methodo, et multorum annorum experientia ſumus conſecuti, non grauatim omnibus communicamus.

DE TREMENTE ET PALpitante pulſu. Cap. 24.

Cor et arteriæ in ſanis nullo alio ciētur motu ſenſibili, quàm diſtēſione et cōtractione, ex quib. pulſus cōſtat. In ægrotis uero ſæpius cor et tremere et palpitare uidetur. Arteriæ hoc nō ita conſpicue oſtendūt. cauſam poſtea declarabimus: tamē

&

Facsimile pages from Joseph Struthius' Edition of 1555
The date does not appear on the title-page in the original, but at the end of the Preface.

tio grauiū acceſſionū in febrib. cum frigore inuadentium: nō in ijs tamen omnib. uel ſolis, ut quis putaret. Reperitur etiā ijs duabus diſſimilis arteriæ figura, quam Græci πδλισιν uocant: Latine depreſſam uel planam recte dixeris, ueluti ſi excogitares circulum exquiſite rotundū in medio paulatim depreſſū. Quod ſi has tres arteriæ figuras characteribus exprimere uelis, iſti erunt. Circularis, ◠ angularis ∩ , depreſſa ⌒ .

Circulus igitur diſtenſionis, ſi multis partib. tactui ſe offerat, altam & latam ſignificat pulſus diſtenſionem: ſi uero paucis ſe offerat partibus, humilem & anguſtam. Sic & lunæ figura, ſi oculis præbet multas circuli partes, qualis eſt ante plenilunium, magnam apparitionem indicat: ſi uerò paucæ uideatur partes circuli in luna, ut fit in trigono, uel tetragono eius ad ſolem, paruā apparitionem demonſtrat. Sic & truncorum caudicum, & lignorum rotundorum in aqua natanitum, paucæ circuli partes, quæ ſupra aquam emergunt, paruam indicant eminentiam: multæ uerò circuli partes, magnam. Atque ita uno eodemq; negotio, ut uides, profunditas & latitudo pulſus, per figuram cognoſcuntur. Quoniam in circulis & globis confuſæ ſunt lineæ dimenſionum: & una eſt linea, quæ & latitudinem & profunditatem tactui oſtendit. Non ſicut in quadratis aut quadrangularibus

cor=

corporibus, ſeparatim cernere eſt profunditatis, ſeparatim altitudinis lineas. Angularis figura arteriæ ∩ ſi multum ſe extulerit ad tactum, altum & anguſtum indicat pulſum: ſi uerò emineat parum, humilem & anguſtum. Depreſſa arteriæ figura ⌒, latum & humilem indicat pulſum. Vides igitur quo modo, dum arteriæ figuram ſenſu percipis, ratio, quæ ſenſui præſtò adeſt, ducit te in cognitionem quātitatis motus: hoc enim ratio dictat, quod magna circuli ſuperficie non circumſcribatur humilis, uel gracilis, uel parua diſtēſio pulſus: nec ſuperficies parua circuli obducatur alto, uel turgido, uel magno pulſui.

Quod ſi contingat, ut ſæpe uſuuenit, arteria digitis occurrere exigua admodū figura, ſiue angularis illa ſit, ſiue circularis, uel potius particula circuli aut anguli: quod fit, quonia motus arteriæ prohibetur aſcendere, & exerere ſeſe ac dilatare, eo quòd accreuerit caro multa uel adeps, uel locus arteriæ humorib. redundet, uel ex alia quacunq; cauſa: difficilis cognitu eſt, uel potius impoſſibilis ad ſenſum, huiuſmodi pulſus, niſi ratio accommodet ſenſui noſtro ſignificationes aliquas certas. Anguſtus quidem ſemper apparet, ex figura, hicce pulſus: ſed altus ne an humilis ſit, neſcitur. Quod ſi quis tactum habeat exquiſitiſſimum natura, in dignoſcendo exercitatum, in

arti=

written descriptions of the pulse, the history of sphygmology would have been much more complete. What the multitude of our predecessors may individually have felt in the pulse is to us, nowadays, mere conjecture. The precision of a Galen in minutely describing the details of his sensations; the freedom of a Floyer in disclosing the limited scope of his own—are almost solitary landmarks. Systematic representations of pulse-sensations do not occur in the entire history of Medicine down to Fouquet, at least in the Western world. Centuries, however, before that date the Chinese had carried out the graphic method, in their own thoughtful, though ever imaginative and grotesque way. They were, so far as we know, the first to attempt delineations of the pulse—apparently intended for didactic purposes.

The important treatise of Struthius contains a few graphic symbols illustrating some of the sensations conveyed by the pulse to the finger. The interest which attaches to them is purely historical. Their author probably never conceived the thought of the system of which they may be regarded as the germ.

The analytical study of the pulse began in earnest with Fouquet's work; but neither his method nor his observations have obtained due recognition; and they have long been buried in oblivion. A second and inferior edition of his book was published in Paris in 1821; and in this country Rucco's * treatise, a feeble reproduction of Fouquet's views and nomen-

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* Rucco (Julius), "Introduction to the Science of the Pulse, as applied to the Practice of Medicine." 2 vols. 8vo, London, 1827.

clature, without any addition whether in the shape of fresh advances, or even of intelligent criticism, served to prove that forty years had not sufficed to make the work bear its fruit, which was to be reserved for a more distant future.

Since Galen, Fouquet was the earliest teacher of an accurate and thoughtful palpation of the pulse, and *in that sense the father of modern tactile sphygmology.* He was the first, and he remains the only, observer who has bequeathed to us the picture of his own personal tactile judgments. Although he did not rise to the conception of Watt's approaching discovery of a method of automatic registration,* nor of its application to the registration of physiological events, still his claims to be regarded as an early pioneer, if not the founder, of the graphic method, in the broader sense, that of delineating the internal phenomena of life, are of no trivial order as may be gathered from the following extract : †

> "Quant a l'institution ou emploi des signes méchaniques, tels que les figures dont nous avons parlé, c'est ici, comme on voit, un instrument nouveau, un surcroit de moyens pour avancer dans la doctrine du Pouls ; c'est en même tems la preuve démonstrative des vérités, que les anciens & les modernes ont enseignées sur cette matière : ces signes devroient, par toutes ces raisons, être précieux . . . .

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* Ch. Ozanam ("La Circulation et le Pouls," Paris, 1886, p. 397) points out that automatic registration was first employed by Ons-en-Bray ("Mém. de l'Acad. des Sciences," Paris, 1734) who used a revolving cylinder in connection with an anemometer ; and that Rutherford, in 1734, obtained thermometer tracings on blackened paper ; whilst Thomas Young invented the method of continuous spiral tracings.

† Henri Fouquet, "Essai sur le Pouls, par rapport aux affections des principaux organes, avec des figures qui représentent les caractères du Pouls, dans ces affections," p. xii. Montpellier, 1767.

Premièrement, j'ai trouvé en parcourant les auteurs, que cette manière de figurer les caractères du Pouls, que j'avois d'abord imaginée de moi-même, avoit déjà été employée par les Chinois ou ceux qui les ont traduits, & par quelques Européens comme Struthius . . . .

Enfin, a l'égard de Struthius, il est aisé de voir que les figures géométriques que cet Auteur a données dans son livre, ne se rapportent qu'à des mouvemens ou oscillations particulières de toute l'artère, dans quelques Pouls irréguliers, tels que le *Vibratil* & le *Convulsif*, & ne sont-là que pour renforcer la démonstration.

. . . .

Les figures exposées dans cet ouvrage, peuvent donc passer pour une invention & une invention utile; elles sont une représentation fidèle, une image sensible & constante des différentes impressions, qu'un court trajet de l'artère fait sous les doigts, par diverses modifications de sa surface & de son diamètre; elles spécifient la forme de chacune de ces modifications, telle qu'elle est apperçue par le tact; en un mot, nous les donnons comme autant de petits tableaux d'après nature, & nous nous flattons qu'ils ne seront point désavoués dans l'observation."

The graphic method has the great advantage of giving dimensions, and therefore accuracy, to impressions. To its practice Fouquet doubtless owed his closer tactile analysis and his keener perception of the palpable features of the pulse, so far in advance of anything that has preceded or followed him, before the date of Vierordt's discovery of the sphygmograph.

II.

Since the Discovery of the Sphygmograph.

The Effects of the Discovery on the Previous Clinical Methods.

In looking back upon the history of the pulse during the last forty years, two things strike us as remarkable. Partly owing to the extreme simplicity of the tactile, and to the relative complexity of the instrumental method, the former has never been given up as a mere traditional rite, or regarded as a placebo rather than a source of definite information. In medical practice there may have been some loss of confidence in the value of pulse observations as compared with the instrumental ones, from a feeling that the hand was outmatched by the sphygmograph. Nevertheless, the old lines have still been followed, and feeling the pulse goes on much in the same way as before.

In the second place, the sphygmograph, which might have been expected to have revolutionised our traditional methods, has not done so. It has not hitherto been developed into a practical substitute for the finger. And, although the services which it has rendered are manifest, it cannot be said to have done as much for clinical medicine as was at first anticipated.

Temporary Discouragement of the Tactile Method.

On the older method of feeling the pulse, the earliest effect was bound to be one of temporary depreciation and discouragement. In presence of the pulse-tracings the finger seemed to be at once disqualified as an instrument of research, as nothing analogous to the tracing seemed to be within its ken. In that direction the touch was plainly incompetent; and it appeared as though, whilst tactile sphygmology might be entitled to respect as an ancient, empirical method, the dignity of an experimental science might be claimed for sphygmography alone.

Indeed, belief in the new invention almost implied loss of the old belief in the finger. That, in this, tactile sphygmology had been wronged, we shall endeavour to show.

Slow Advance made by Sphygmography.

It must be acknowledged that, important as are the theories and facts for which we are indebted to it, the sphygmograph has been very slow to extend our practical knowledge of the subject, and has furnished the clinical method with relatively small practical assistance, hardly comparable with the advances effected by the stethoscope, indeed, not raising tactile sphygmology much above the level it previously occupied. This lack of helpfulness has its significance. There has been but a scanty supply of facts clinically available, in spite of a more abundant harvest in the field of physiology.

Here again the sphygmograph has been rather disappointing, and we have cause to wonder that so short a curve as that of a pulse-wave should have puzzled men of science for fully forty years; and that after miles of sphygmographic tracings we should still be engaged in the work of analysing and of interpreting the elementary features of the sphygmogram. The conclusion is unavoidable that many a good thinker may have been delayed by sphygmographic riddles; and that we may have been kept from investing in the study of the tactile pulse some of that attention which may have been less profitably bestowed.

CHAPTER II.

THE SPHYGMOGRAPH AND THE FINGER.

CAUSES OF THE LACK OF CO-OPERATION BETWEEN THE TWO METHODS.

WE shall find two sets of explanations for this slow advance of sphygmography, and for the want of a working sympathy between it and the tactile method :

A. Differences in the Procedure and Circumstances.

(1) In their performance the two procedures are totally dissimilar, the one being so easy as to be almost at times unconscious, the other needing time, skill, and much care.

(2) In the nature of the observations, there is nothing in common : on the one hand we have a tracing ; on the other a feeling ; and tactile sensations are difficult to express in lines.

(3) The attendant circumstances are also dissimilar. It is the natural function of the hand to feel ; but the tracing obtained is instrumental, automatic.

(4) Lastly as regards results, the sphygmogram is something entirely different from that which the finger feels ; it needs interpretation, and it also needs

correction : indeed, as we shall see, the pulse tracing requires mental education and mental activities of a high order to re-establish a parallel between the perception and the tracing.

B. Essential Difference between the Sphygmogram and the Pulse-Wave as Felt.

The sphygmograph cannot trace the feeling of the pulse ; neither can the finger feel the pulse-wave such as the sphygmograph describes it.

In truth the two things are of different order. The tracing has but two dimensions ; the pulse-wave has three, though two of these only can be felt completely. The tracing has a surface in the vertical plane; it is a vertical section, or elevation; whereas the pulse has for its surface the cylindrical surface of the artery, the variations of which are in part felt, and in part estimated by comparing the stages of arterial contraction and relaxation. The cylindrical surface remains under the finger throughout—as a background for the modulations of tactile impressions due to the secondary oscillations in the downstroke.

Even this is only an approach to feeling things as they are. The pulse-wave is only felt completely after dissection in a living artery, which can then be encircled by the fingers.

Although we shall probably never revert to Fouquet's graphic method, which represents the artery in its three dimensions, there can be no doubt that the touch provides us with a much more substantial and "solid" idea of the pulse-wave than does the sphygmograph. Some means may yet be devised of transmitting to paper some of the "solid" tactile impressions which the finger perceives.

The Unreal Features of the Sphygmogram.

The sphygmographic "wave" is avowedly, though we are in danger of overlooking the fact, an artificial product. At best sphygmographic tracings are but conventional records of the arterial events conveniently abbreviated. Like most abbreviations, they need to be interpreted.

When, in drawing a likeness, we diminish or increase certain features out of proportion to others, the product is a caricature. The sphygmogram is obtained somewhat after that process.

A single pulse-wave occupies a length of about 30 feet: we devote to its representation about half an inch. Instead of diminishing its height in proportion, we magnify it, more or less, according to the length of the lever, some fifty times. The mind can hardly follow the corrections which so extreme a distortion would necessitate to make the tracing resemble the natural pulse-wave. Never having seen the pulse-wave itself, we are spared all sense of the ridiculous. Nay, the sphygmogram has usurped in our minds the place of the pulse-wave: to us it is the more familiar of the two.

The sphygmogram is indeed the only graphic representation of the arterial-pulse in clinical use, and from it is at present evolved our visual, and in most cases probably also our mental ideation in connection with the pulse-wave.

Failure of the Finger to Realise them.

Meanwhile the touch is tied down to unadulterated facts. Though we may try, we fail, with the finger, to identify things as they are displayed in the tracing. The mental product of the attempted equation could only be a *tertium quid*, itself artificial, uncertain and indefinable ; and in what proportions each individual observer may combine the two types in this shadowy compromise, is as inscrutable as his consciousness.

By the great majority, if not by all of us, much of the tactile detail of the pulse has been overlooked in the endeavour to express the pulse as a whole in some adequate formula—too often figurative. So at least we interpret the singular neglect in which the pulse-sensations have remained.

The Relative Value of the Finger and of the Sphygmograph in the Reception of Pulse-Impressions.

As a recording instrument the finger has not hitherto been utilised for the graphic method. It does not enter into competition with the sphymograph in that capacity ; but can only be compared with it as a receiving instrument. The sphygmograph works against varying pressures with a *constant* energy—the finger, with *varying* energies. In this the finger enjoys theoretically a great advantage. Any given pressure of the sphygmograph which is most perfectly adapted for some one of the events of the pulse wave, will be much less adapted for all others; whereas the touch is not limited by any rigid scale of pressures. Yet there are special circumstances which lessen this theoretical facility.

(1) The range of pressure suitable for fine feeling is a limited one, varying with individuals, varying with the state of the skin, its temperature, moisture, etc., and varying also with education,—but essentially limited. Thus, a pressure which might, in the sphygmograph, bring out a certain event of the pulse may, if applied by the finger, be just great enough to impair finer perception.

(2) Even with the advantage of experience, the rapid adjustment of the finger to that degree of pressure which, whilst bringing out the event to be felt, also favours perception, is extremely difficult. It will be convenient to refer to this operation under the name "accommodation for touch."

(3) Although the discriminating power of the finger-tip for points of contact is delicate, its discrimination for pressures is of a coarser kind, and needs the employment of a larger tactile surface than the surface required for the instrumental determination of variations in pressure.

(4) It will be seen later on that the unavoidable employment of a large surface of the pulp leads to a multiplicity of impressions which may confuse.

(5) In feeling the pulse the accommodation for touch is probably directed in all of us to the ictus. The very fact of this being successfully felt means loss of accommodation for the perception of the events which follow, and which are carried out at a much lower level of pressure. Not only ancient

writers, but even the latest authority, von Frey,* deny the possibility of the contraction of the artery being felt. The truth is that the power exists, but we have not known how to employ it.

The disadvantages of the sphygmograph as an instrument of reception are foreshadowed in what has just been stated :

(1) The accommodation is a fixed one ; and as we all know, according to the degree of pressure selected, very different tracings can be obtained from one and the same subject.

(2) The sphygmograph suffers, even more than the finger, from the difficulties connected with the local conditions of the artery. This is so surrounded with soft parts, and therefore liable to transmit pressures to them, that pressure applied to it over a very limited surface, for instance by the point or the edge of a knife, would not convey to the lever the entire effect. The broad button which has to be used in consequence, conveys more than belongs to the thin vertical section of the artery supposed in strictness to be alone under observation. This circumstance seriously interferes with the efficiency of the sphygmograph as an instrument of analysis. At this early stage it is almost premature to state, although we hope in the sequel to prove, that, at least in some directions, the finger possesses finer discrimination than the sphygmograph.

For the present we possess a partial explanation for the relative failure of the latter in the imperfections which have already been pointed out, including those faults which lend artificial features to the sphygmogram, viz. :

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* "Die Untersuchung des Pulses," Berlin, 1892, p. 40, "Ueber die Art der Zusammenziehung der Arterie sagt das Gefühl Nichts aus, nur die Nachschlaege, wenn solche vorhanden sind, werden gespürt."

(1) A diminution of the velocity in an arbitrary fashion—in other words, the shortening of the pulse trace ;

(2) An increase, entirely arbitrary, of the vertical dimension ;

(3) The rigid nature of the force or weight applied : this tells nearly equally on the pulse at every stage, whereas digital pressure is accommodative ;

(4) The linear conversion of any forces bearing on the surface of the lever, whatever be their actual mode of application. From this point of view no form of button can beat the finger as a collector of impulses.

PART I.

GENERAL NOTIONS ON PULSE, ARTERY, AND ARTERIAL TENSION.

CHAPTER I.

WHAT IS MEANT BY "THE PULSE"?

The Visible Pulse, the Tactile Pulse, and the Modified Pulse.

By "Pulse" we mean: (1) The throbbing of arteries which may often be *seen* and is then manifestly *objective.* (2) We also mean the throbbing *felt* by the finger when placed on an artery:[*] this is the *objective pulse-sensation,* less objective than the first only in that the sensations cannot be identical in all observers. (3) The pulse-tracing, or sphygmogram, is another aspect of the pulse, purely objective, but modified by the instrument. It is the best exponent of a third idea included under the general term "pulse"—viz., the *modified* or partly factitious pulse; to us the most important, since in the act of feeling the pulse, we are inevitably modifying it.

In discussions relating to the pulse, the mind is too apt to wander from one to the other of these acceptations; but in common language, the word "pulse" conveys the least definite of these ideas—viz., that of the tactile pulse sensation.

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[*] "The pulse is that sensible motion which is given to the artery by the blood, which the heart injects into it" (Sir John Floyer, *loc. cit.*, p. 14).

The Pulse as an Intra-Arterial Event, or Pulse-Wave.

(4) Lastly, we have no difficulty in forming a clear conception of the pulse as an intra-arterial event, independent of the observer. The heart contracts: thereby a wave of increased pressure is set up in the arterial stream; this we call the *pulse-wave.* It is the pure or non-modified arterial pulse; but as soon as it is approached, whether with the sphygmograph or with the finger, our uncertainty begins. Is their report trustworthy? To what extent have they modified the pulse? These questions are almost unanswerable. Some distrust the finger more, others the sphygmograph. Both are really trustworthy, each in its own province; but the larger province belongs to the finger.

THE TACTILE PULSE. WHAT IS IT?

In its simplest form the tactile pulse may be regarded as the sensation communicated to the finger (applied with sufficient pressure to steady, but not to deform the artery) by the combination of a slight expansion and of a considerable tension (*hardening*) of the arterial wall by the wave of blood pressure.*

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* Distinct from this elementary sense of pulsation are the *various modified pulses* brought about by varying the degree of pressure of the finger. These will be studied in the analytical section, p. 96. They will be found to differ among themselves almost as much as from the elementary non-modified pulse.

A view has been ably supported by Sir William Broadbent ("The Pulse," p. 19) * that the feeling of pulsation is the result of pressure by the finger; and that, apart from this pressure, there is no excursion. According to this, pulsation would consist in a return to the normal cylindrical condition, from the state of flattening induced, during the interval between systoles,† by extra arterial pressure.

Sir William Broadbent's theory is not only ingenious, but in great measure borne out by facts. The pulse cannot be felt with efficiency without putting upon the artery a degree of pressure sufficient to partly flatten it. The tactile pulse is, more often than not, a modified, and, in that sense, a manufactured pulse; and it is the special object of this work to enter a little more closely into the study of these modifications. It cannot be doubted that the finger is capable of obtaining much stronger pulsations by partly compressing the artery, and then allowing itself to be lifted by the systolic pulse wave, than under any other circumstances.

Compression not Essential to a Perception of the Pulse.

Beyond this, however, most observers would not be prepared to go; and they will be inclined to regard the pulse as produced within the artery, and as merely intensified by manipulation. Deformation of the artery is not essential for the perception of its

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* "The Pulse," by W. H. Broadbent, M.D. Cassell and Company, London, 1890.

† A similar view was suggested by Marey ("La Circulation du Sang à l'état physiologique et dans les Maladies," G. Masson, Paris, 1881, p. 205).

beat. All that is needed is contact with the finger, and counter-pressure by bone (or better still, by soft parts), sufficient to prevent the artery from jerking away from the finger.

Marey compares the pulse to the sensation of the cardiac apex-beat, conveyed by the hardening of the heart's muscle, to the finger which is depressing its surface. One may suggest, however, that the perception of the apex-beat is not necessarily bound up with any dimpling of the cardiac surface by pressure. The hand may be laid flat across the ribs, and in a lean subject the visible cardiac beat will rise up to it, as the visible arterial pulse rises to the flat ofthe finger laid across the wrist, and resting upon the bone and the tendon.

Marey's other simile—that of the hardening of the abdominal parietes during straining (*loc. cit.*, p. 141)—likewise supports our own view. If the flat of the hand be steadied on the anterior superior iliac spine, in such a way that it touches the abdominal surface without causing appreciable pressure, the act of strain will be felt to raise as well as to harden the abdominal surface.

More direct, perhaps, than any other form of proof, is the simple method of grasping, from the dorsal aspect, with the left hand, one's own right arm two-and-a-half inches above the wrist, in such a way that the base of each terminal phalanx rests flat on the outer edge of the radius. If the finger-tips be gently advanced till they touch the side of the artery, the latter will be pushed out of its position, but, at the same time, its pulsation will be felt, although obviously no flattening is induced, and although counter-pressure is made by soft parts only, and not by bone.

In elastic arteries, though not in those which have become rigid,* all that is needed for the perception of the tactile pulse is, that the artery shall be fixed, and maintained in due contact with the finger by some firm support such as that of the tendons in the last experiment.

Proofs of the Independent Pulsation of Arteries.

The following are reasons for adhering to the view that the pulsation of arteries is an active expansion, not one indirectly brought about :

(1) Aneurysms which become superficial give a more or less extensive, distensile pulse.

(2) Large arteries, and especially the abdominal aorta, may give an expansile pulse, perceptible on applying the hand without pressure, and often perceived by the patients themselves as an internal sensation.

(3) Capillaries in certain conditions dilate with the pulse ;—so at least we are bound to conclude from the considerable increase in the redness of the part, which mere rise in pressure could not effect ; we must admit that, in this case, the colour deepens because a larger surface of blood is exposed owing to the pulsatile widening of the calibre of each capillary. Therefore, our touch is probably not deceived in its impression that the radial artery, intermediate in size between the aorta and the capillaries, dilates as they do, during pulsation.

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* In this connection, see p. 26.

(4) If the finger be very lightly applied, so as not visibly to dimple the skin, the alleged flattening is out of the question, and yet, in an ordinary lean subject, a distinct pulsation will be felt.

(5) Further proof is obtained by watching closely the skin over the wrist, the latter being placed in moderate flexion, or, in the case of the ulnar artery, in extension. In thin subjects, the skin will be visibly raised by the artery at each systole of the heart, even when it has been ascertained that the artery is not the subject of locomotion, as is apt to be the case in disease and as the result of age.

(6) Dr. Sansom and myself have independently obtained experimental proof that arteries undergo systolic increase in their diameter. This can be demonstrated by applying very fine callipers to any accessible artery.* For this purpose the brachial is convenient; by flexing the elbow it can be made to stand out as a loose pulsating loop. This evidence serves, too, as a confirmation of the testimony of touch which gives us the impression as though the arteries swelled up under the finger at each beat.

We may, therefore, regard the commonly accepted view to be the correct one, whilst recognising that a greater excursion of the feeling finger can be obtained by depressing the arterial surface during diastole, and allowing its full recoil during the systolic beat.

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* The transverse expansion of arteries had been demonstrated by Spallanzani, by slipping round the artery a loose ring just large enough to fit the vessel during its distension, but visibly too wide for it during its contraction. Flourens used a small circular spring the two ends of which were forced apart by the expanding artery. Poiseuille's method consisted in watching the movements of a column of fluid in which the beating artery was immersed (see Marey, *loc. cit.*, p. 197).

These are also the conditions realised, though imperfectly, by the button of the sphygmograph.

Spontaneous Pulsation Suppressed in Rigid Tubes.

In atheromatous or calcified arteries, the conditions are different: there may be considerable volume of the artery, and yet feeble pulse, whilst arteries of more moderate size may yield extensive pulsation. This difference is capable of being explained.

In rigid tubes, a glass tube for instance, no pulsation could be seen, although the pumping force might be equal to that of the heart. The rhythmic expansion of the arterial wall is the result and the expression of the elasticity of the tube; and we may speak of this visible expansion as the objective pulsation referred to in previous remarks.

Conversely, a membranous tube, originally elastic, if sufficiently thickened by overgrowth, or if sufficiently stretched by its own contents, may lose so much of its elasticity as to pulsate feebly or not at all. This same tube will yield a throbbing if any part of its outer surface be dimpled in by the pressure of a rod, with just enough force to overcome the pressure stretching its walls. The rod will then perform movements analogous to those obtained when the finger is applied to an elastic artery. In this case the pulsation is not spontaneous. It depends upon interference on the part of the observer, and in that sense may be regarded as manufactured.

This experiment lies at the root of Sir William Broadbent's explanation. Some arteries are so tense, that their pulse is only obtained by the application of full pressure. The object of this pressure is not so much to flatten the artery, as to eliminate its wall-tension, and thus to give scope to the contained waves of blood pressure. As soon as the wall is relaxed, pulsation becomes manifest.

The Spontaneous, and the Factitious or Artificially Magnified Pulsation.

Thus, there exists a pulse which is factitious, as well as a genuine spontaneous objective pulse. The term *subjective pulse* must of course be reserved for the sensations of inward throbbing of which patients often complain.

Intermittent pressure applied to an elastic tube would supply us, even although no spontaneous pulsation was occurring within it, in turn with two alternating sensations : that of the flattened, and that of the fully expanded tube. These variations in size, merely factitious in the preceding cases, may also be obtained in the pulsating artery by varying our pressure with each succeeding phase, so as to obliterate it when at its lowest. In this way we magnify the beat at the expense of the diameter of the artery itself; part of the upstroke and downstroke obtained is then due to the passive excursion of the arterial wall under intermittent pressure from the finger.

May we not conclude that, whether consciously or not, each observer so carefully adjusts his pressure, that it suffices to depress the artery during the intervals between waves, but not during their passage? We shall revert to this point later on.

CHAPTER II.

THE ARTERIAL WALLS. THEIR ELASTIC AND MUSCULAR FUNCTIONS.

Tactile Characters of the Arterial Surface;

Smoothness or Roughness.

THE *outward* smoothness special to arteries is not readily appreciated by the finger except as part of a smoothness and softness of the entire wall, and any unwonted roughness, hardness, or irregularity within the wall is felt as though it were superficial. The *thickness* of the wall may be ascertained by alternating digital pressure with relaxation; but, unless thickened, the artery when compressed will be lost to the touch among the other soft parts. Rolling the artery from side to side, or sliding the finger up and down its course, are the usual modes of testing the thickness of the wall. When considerably thickened, the artery not only can be felt, but can be *rolled* under the finger like a cord; and, if calcified, it will continue to yield the impression of a cylindrical body, even between beats.

Consistence.

By a combination of the impressions derived from testing the surface of the artery and its thickness, some estimate can often be formed of the structure of the wall. *Firmness without hardness*, analogous to the feeling conveyed to the touch by an india-rubber tube, suggests muscular and fibrous thickening. Hardness of surface coupled with a cylindrical and cord-like feel indicates atheromatous thickening, or calcareous infiltration. The latter change is certainly present if, in addition, the artery be uneven and ribbed like ipecacuanha-root.

Compressibility and Softness; or Incompressibility and Hardness.

Hardness[*] and incompressibility are always associated.

An excised artery, forcibly injected, and tied at both ends, could not be readily flattened by pressure, the fluid confined within it being practically incompressible.

If the excised artery be allowed to remain empty, very slight pressure will suffice to collapse it. This shows that, in compressing a pulsating artery with the finger, very little pressure is expended in flattening the walls, the bulk of it being used in damming up the blood current.

Absolute incompressibility, as well as absolute hardness, belongs to rigid (*i.e.*, calcified) arteries. In them the blood-pressure may be, and usually is high, but local arterial contraction has no share in its production. The hardness and incompressibility reside in the coats, and persist after death.

Relative incompressibility may be due to arterial

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[*] *Cf.* p. 46

[illegible] Chirurgical Society

tension. In simple cases of so-called high tension the arterial wall possesses no hardness of its own. The excessive blood-pressure alone renders it hard. The feeling of hardness varies with the pressure, just as any yielding tube feels lax, firm, or hard according as the water it may contain nearly fills it, quite fills it, or fills it to distension. Thus, when very tense, a pulse resists compression and feels hard: yet after death the arterial wall may be found normal or only a little thickened: its hardness and incompressibility belonged for the greater part to the contained blood, and have disappeared with its escape.

The Elastic Coat, and the Elastic Function of Arteries.

The elastic force can only be called forth by a previous distension or by a previous constriction beyond the position of rest, or normal calibre. Any reduction in size below the normal calibre must be the unaided result of muscular contraction: the elastic coat could only oppose it. In the aorta, where the elastic element vastly preponderates, the power of stretch and of resilience can be readily tested. We owe to Professor Roy some important data in this direction (*Jour. of Physiology*, vol. ii.).

Very little is known concerning the various influences which probably modify the properties of the elastic membrane, beyond those which Roy has pointed out.

It should be borne in mind that the muscular coat, besides its contractile power or tone, also possesses an elasticity of its own varying with the degree of its contraction, and capable of bearing some share in the elastic reaction.

The Muscular Coat and the Muscular Function of Arteries.

Compared with those of the elastic coat the properties of the muscular coat are complex:

(1) It is elastic; but its coefficient of elasticity varies with each stage of its contraction.

(2) Its higher function, that of contractility, if less rapid in its response, is much more adaptive than the passive function belonging to the elastic coat. It is ultimately under the control of the nervous system, at least as far as "muscular tone" is concerned. This is proved by the results of section and of stimulation of the spinal cord.

We may assume that the properties of the unstriped fibres of blood-vessels are, in a general way, analogous to those of other smooth elastic fibres.

The Muscular Irritability and Contractility of the Muscularis.

The effects of direct stimuli of every description in producing contraction of the arterial wall and of the arterial lumen have been demonstrated by a variety of observers. Verschuir[*] was one of the first to trace the effects of mechanical stimulation, by rubbing the femoral artery of a dog with the handle of a scalpel.

We shall have occasion (*vide infra* Experiment xxv.

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[*] Verschuir, "De arteriarum et venarum vi irritabili," p. 89 (quoted by Ozanam, *loc. cit.*, p. 309).

p. 164) to refer to Marey's * observation on the depression or loss of excitability which quickly follows upon severe stimulation; the tendency of moderate stimulation being to produce arterial contraction, that of excessive stimulation to produce dilatation.

The predominance of the muscular coat and of muscular contractility in the *smaller arteries* was pointed out by J. Hunter, who also demonstrated in the umbilical artery the long persistence of contractility after separation of the vessel.

It can easily be demonstrated on the radial artery that some delay occurs between the stimulation and the arterial contraction.

The Pressure-Regulating Function of the Muscular Coat.

The muscular coat is certainly not concerned in the production or regulation of arterial pulsation. The following passage from Sir John Floyer's work † would correctly express its relations to pulsation, if the words "retracted" and "retracts" were to be substituted for "contracted" and "contracts":

"The artery, after its dilatation by the blood injected, is again contracted by its own annular fibres; but the artery contracts no farther than the impulse of the blood had distended it, which is only a restitution of the distended fibres to their natural tone, rather than an entire contraction."

On the other hand, we may look upon the muscular coat as to a large extent regulating the calibre of arteries. We know enough to recognise its great importance; but the precise mechanism, the circumstances, and the time-relations of its work are matters of which we are still profoundly ignorant.

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* Marey, "Mém. sur la Contractilité Vasc." (*Ann. des Sc. Nat.*, 1858, 4^{me} série, t. ix. p. 69).

† *Loc. cit.*, p. 17.

Arteries may contract merely to adapt themselves to the lessened bulk of their contents. In this case blood-pressure is not raised. A demonstration of the fact that arterial contraction is capable of raising the blood-pressure was long since supplied by Poiseuille's * determinations of the relative forces of contractility and of arterial elasticity. In the horse, the former was found to surpass the latter by 24 mm. Hg.

The vasomotor nervous mechanisms take a large share in the pressure-regulating function. At the same time it is no longer doubted that, even without reckoning such exceptional instances of independent pulsatile rhythm and vascular contractility as those presented by the bat's wing and the rabbit's ear, etc., local mechanisms exist for the regulation of the calibre of artèries; and that the muscular coat itself may be regarded as possessing the power of self-regulation.

Muscular Contraction and Muscular Tone; and their Relation to Blood-Pressure.

Analogy bids us look in the arterial membrane for the two forms of muscular contractility with which we are familiar in other muscles, viz., muscular tone and muscular contraction, for we recognise two varieties of arterial contraction, very different in degree, and differ-

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* Poiseuille, "Recherches sur l'action des artères dans la circulation artérielle," *Journal de Physiologie*, par F. Magendie, 1829, t. ix. p. 44 (quoted by Ozanam).

ing also in their permanence. In extreme instances their relative peculiarities and effects are in striking contrast. The lesser degree, which we may call "arterial tone," is mainly adaptive, keeping up a due proportion between blood-volume and arterial calibre, and persisting. The other degree is "arterial spasm," which disturbs this harmony; raises blood-pressure; and is apt to appear and disappear, with comparative rapidity.

Whilst, however, like that of other smooth fibres, the contraction of the arterial muscle is slow to develop and slowly accomplished, such is the rapidity of the heart's contraction, that, as regards time, the occasional arterial contraction and the permanent one are both in the same relation to the pulse-wave: they both outlive the duration of any single pulsation; their action on the pulse would be in both cases precisely similar, the difference being chiefly manifest in the degree of the constriction, and in its effect on blood-pressure.

Just as in other muscles, whether visceral or skeletal, the arterial muscular condition may be (1) of normal tone; (2) of abnormal tone; or (3) of spasm.

A *normal tone* would maintain a moderate muscular resistance to internal pressure.

A *diminished tone* would imply low intra-arterial pressure, giving rise to little cardiac stimulation and to feeble resistance of the muscular coat.

Any *increase in tone* beyond the normal would entail an increase in the muscular resistance, and would necessitate greater driving power. Thus, proportionately with the increase in vascular tension, the blood-pressure would rise.

Lastly, *arterial tetanic spasm*, such as to cause considerable diminution in calibre, whilst raising the tension of the arterial wall and the blood-pressure, would reduce considerably the internal arterial surface exposed to pressure, and the oscillations of calibre due to pressure.

Summary of the Functional Relations of the Elastic and of the Muscular Coat of Arteries.

In conclusion, we conceive that to each artery belongs a normal calibre (seen after rigor mortis has passed away), which it is the office of the muscular coat to modify, and of the elastic coat to restore. Any contraction of the calibre below the normal size involves antagonism between the two coats. On the contrary, any distension of the artery causes the two coats jointly to suffer dilatation, and jointly to resist it.

The elastic coat prevents over-distension, and, on the cessation of tension, reduces the artery to its average size; but, by means of its muscular coat, the artery can also assume smaller sizes and maintain any given calibre, so long as the muscular tone is kept up. Thus, within a certain range of movement, the muscular work overlaps that performed by the elastic fibres. The muscular coat, even apart from any contraction, passively reinforces the latter. On the other hand, it is capable of actively constricting them, in spite of their tendency to re-expand. Besides co-operating in the work of the elastic coat, the muscularis may thus have for its duty to save it from the strain of excessive stretching; and, by constricting the artery, to allow the over-

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stretched fibre to rest at times and to regain its spring. This would be, in current language, a kind of *massage*, practised on one coat by the other for the purposes of nutrition.

With an elastic coat tending to recoil from states either of distension or of constriction to the position of rest; and with a muscular coat capable of allowing distension of the elastic fibres by blood-pressure, or of reducing the arterial diameter to such an extent that the elastic fibres undergo constrictive tension, or lastly, of adapting itself to any of the sizes which are within the range of the elastic function, the artery becomes capable of assuming a variety of diameters without ceasing to resist pressure. Having been set by these mechanisms to any given size, the arterial wall may or may not be made tense by the greater or less volume of blood, or strength of the heart beat.

The Influence of Age on the Arterial Function.

Since, in advancing age, the muscularis frequently becomes the seat of calcification, we must regard the muscular function as tending to become obsolete and its elasticity to vanish, as a senile result. There are reasons for regarding early adult life as the period of highest muscular contractility, and childhood as that of highest elasticity of arteries. The latter conclusion is established by Prof. Roy's investigations.

CHAPTER III.

THE ARTERIAL CHANNEL — ARTERIES VIEWED IN THEIR CONTINUITY—PRESSURE CHANGES AND PULSATILE SYSTOLIC CHANGES IN ARTERIES.

Arterial Fulness.—Rhythmic Variations in Arterial Diameter, and in Thickness of Arterial Walls.

"Fulness and emptiness" of the pulse are figurative expressions. Arteries during life are always full, though not always full-sized. The size of the artery varies with the bulk of its contents; and this adjustment is brought about by two forces—the elastic, and the more elaborate muscular, mechanisms of its coats.

A voluminous pulse is usually found in perfectly *collapsible* and elastic vessels. A *non-collapsing* pulse may be moderately large; more often it is of rather small size, neither expanding much with the pulse-waves, nor materially contracting during their intervals. This condition will be again referred to (see p. 47). Should any ordinary pressure from the finger fail to flatten the *tensely filled* artery, the latter is then described as cylindrical and "non-collapsing," since it continues to be felt after the pulse-wave has ceased.

Thus, an artery may be large and tense, or it may be small and tense. In the first case the wall would be more or less stretched, and relatively thin; in the second it is contracted, and thicker by so much. In the first instance the tension is due chiefly to an increase of the contained blood; in the latter, also in part to the contraction of the muscular coat and (if the contraction be habitual) to its hypertrophy. The share taken by muscular contraction in the production of high tension explains the frequent association of the latter with a small diameter and with thick walls.

Mean Arterial Calibre—and Mean Arterial Tension.

An artery thickened almost to obliteration, hard, and incompressible, and another artery thin-walled and readily compressed, may both possess after death the same external diameter. Any estimation of their calibre during life would largely therefore have been based on inference.

The mean calibre of rigid arteries is more easily guessed at than that of elastic arteries. The biggest waves are apt to occur in the most elastic arteries, which readily collapse during the intervals between beats. Since their phase of enlargement alone is fully perceived, it is difficult for the finger to form an estimate of their "mean calibre."

If a very large wave be propelled with great suddenness into a relaxed artery, the feeling will be one of hardness in spite of the elasticity of the vessel. A heart-wave of this kind occurs in the so-called water-hammer pulse, which presents moments of tension alternating with longer periods of great laxity. This is the typical pulse of *ill-sustained high arterial tension.* The typical pulse of *sustained arterial tension* is met with in interstitial nephritis. In this instance, if there should be continued spasm of the muscular coat, the pulse-wave will yield very limited oscillations.

The Adaptation, by Means of the Muscular Coat, of the Calibre of the Artery to its Contents.

Automatic stimulation to contraction is probably exerted on the muscular coat by the blood-pressure, somewhat as skeletal muscles are mutually kept tense by their antagonists. At any rate, we observe that the artery adapts itself to its contents and keeps in touch with them, even when their volume is much reduced. By this means some remnant of blood-pressure is preserved at all times within living arteries, and the blood-flow is kept up. Had this adaptation failed, the blood-pressure might at times have become negative; but any suctional effect of this sort is entirely obviated by the active contraction of the muscularis, which, however much the blood-stream should lessen, keeps, as it were, a grip upon it.

It is also possible for arterial contraction to occasion a rise in the blood-pressure. The muscular activities would then exceed the function of adaptation and partake of the nature of spasm. Their cause would no longer be intrinsic and local, but of distant and often reflex origin. In those cases the lessened arterial lumen is not an indication of a lessening bulk of the aggregate arterial contents; the artery contracts upon an abundant blood-stream, thus not only directly raising blood-pressure, but indirectly stimulating the heart to an increased systolic energy.

In a word, the lumen of an artery bears no fixed relation to the blood-pressure within it; and a small pulse may be associated with opposite cardiac conditions. Thus smallness of calibre, which may be an indication of cardiac weakness (with too little blood), may also, and often does, coincide with excess of blood-pressure and of arterial tension. This is illustrated in Fig. 1.

But a pulse is often large as well as tense, when the heart is hypertrophied; and when a narrowing of the capillaries and arterioles rather than of the arteries is the cause of the heightened pressure. Assuming that the blood-volume was normal, it is plain that free elastic oscillation and a relatively low blood-pressure and arterial tension would coincide with a large arterial calibre; and that set contraction of the calibre would be associated with lessened manifestation of elasticity, and often with a rise in blood-pressure and in arterial tension.

Elongation and Tortuosity.

The course of an artery may be straight or tortuous. Normally present in the arteries of parts apt to vary in length, bulk, or position (limbs and viscera)—or as a safeguard against too forcible and direct a systolic impact (brain and organs of sense, etc.), tortuosity in other situations is an indication of senile change. It is much more marked in cases combining with the senile changes those resulting from kidney disease and atheroma. So long as arteries are young and elastic, and habitually free from distension, their transverse expansibility will be such as to absorb much of the recurring systolic charge, leaving under ordinary circumstances little occasion for elongation. With the progress of years arterial elasticity will lessen, but the loss will be greater in the transverse than in the longitudinal direction; and the increasing systolic force of the heart will produce more and more *pulsatile elongation,* in addition to the *permanent elongation* kept up by the mean blood-pressure.

I. The Alleged Systolic Elongation of the Aorta.

It is still a question whether the aorta may undergo elongation, or the arch of the aorta any alteration in its curvature, during the cardiac systole, as a result of the ventricular contraction. The systolic rise felt in the episternal notch of subjects with a short thorax is regarded by some as an instance of the pulsatile locomotion of the arch. An argument in support of the theory of systolic elongation of the aorta has also been based on the fact that, in spite of the systolic change in its diameters, the heart remains permanently in contact with the same spot of the chest wall. Ceradini, a strong advocate of this view, which presupposes a neat compensation between the aortic elongation and the cardiac shortening, owns that it is not shared by all observers, and that some of their experimental results oppose it.

Considerable dilatation of the first portion of the aorta is common, but any independent elongation of the arch such as to materially modify anatomical relations is practically unknown to pathologists. Again, irregular thinning occurs in the coats of the descending aorta, with resulting local bulgings or aneurysms; but the vessel is never so much elongated as to become sinuous.

The author has elsewhere expressed a view that the cardiac systole itself exerts a directive and a steadying influence on the origin of the aorta. Any upward bulging of the transverse portion of the arch is prevented by the origin and vertical direction of the three large trunks destined for the head and neck; and the thoracic and abdominal aorta are maintained vertical by their close attachment to the spine.

Owing to this steadying of the transverse portion by the great vessels of the neck above and by the right pulmonary artery below, the ascending portion is the only one free to undergo elongation; but, as already stated, we are not familiar with elongation as an independent change, although, whenever much dilatation exists, the longitudinal dimensions of the wall must also increase.

II. The Pulsatile Elongation of Arteries.

In the peripheral arteries elongation is a very frequent change; indeed, in old age it is a normal feature. Its causation from intra-arterial pressure admits of no doubt. The action of excessive fulness and pressure in producing elongation of relatively weak vessels is well seen in the progressive tortuosity of varicose veins in the usual situations, and of anastomotic veins of the abdominal wall resulting from pressure on the vena cava, and also of the veins in arterio-venous aneurysms.

In arteries we recognise the same mechanism of production, because elongation, as a senile change, occurs concurrently with increase of vascular tension; but a more direct proof is that afforded by the visibly elongating effect of the pulse-wave. This can be observed in the wrist of any person far advanced in years, but more particularly in those of lean habit and the subjects of chronic renal disease. The same process is seen, in often striking degree, in sufferers from aortic valvular regurgitation. In all these cases the sinuous state of the arteries is permanent; but at the moment of the beat distinct locomotion takes place; and where decided curves pre-exist, they undergo a strong succussion, and sometimes considerable displacement.

It appears probable that arterial elongation is brought about for the greater part by an exaggeration of the normal curves wherever they occur.

The Natural Curves of Arteries.

As we have previously stated, sinuosity is characteristic of some arteries, particularly those such as the temporal and intra-cranial arteries, and the arteries of the organs of sense, in which relatively large pressures require to be held in check. Again, the arteries of very muscular parts are endowed with a natural looseness or sinuosity which renders them easily adapted to the varying contraction and relaxation of the muscles, and to the varying lengths of the limb or part. The sinuosity is sometimes seen even in extension of the limb; with flexion it becomes very prominent—as, for instance, in the brachial artery. At the bend of the elbow this vessel forms, when the arm is flexed, a large loose pulsating loop. Clinical interest attaches more particularly to the natural and pathological curves observed in the radial artery at the wrist, and to these we shall have occasion to refer in greater detail.

Pulsatile Locomotion of Arteries.

Marey describes* a longitudinal variety of locomotion as well as one by *lateral incurvation.* The first may be seen when, by strong flexion of a limb, the artery (as the brachial at the elbow) is thrown into so great a curve that the upper part of the vessel can work up and down upon this as upon the extremity of a horseshoe-shaped spring; but its best demonstration is that given by the systolic protrusion of the main artery from the face of a fresh stump. The other variety is of every-day occurrence as a senile change. It is so obvious that it was erroneously regarded as the cause of the pulse (by Bichat). These phenomena are demonstrations of the fact that arteries possess considerable extensibility in the direction of their length.

The systolic elongation will throw into curves the previously straight line of an artery. Any pre-existing arterial loop will be forced into a larger curve, after the mechanism seen in a Bourdon's manometer; and the change will sometimes be accompanied by a swerving of the loop as a whole from one side of the main axis of the vessel to the other.

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* *Loc. cit.*, p. 196.

As an additional proof of this tendency to elongations, Marey instances the fact that, when a limb is amputated, a much stronger pulsation of the artery is observed after deligation than previous to it. This is an important observation, which will claim our attention later on.

CHAPTER IV.

ELEMENTARY NOTIONS OF ARTERIAL TENSION AND ARTERIAL BLOOD-PRESSURE.

What is Arterial Tension?

TENSION of a membrane implies a stretching force; the force which stretches the artery is the blood-pressure. Arterial tension and intra-arterial pressure are thus closely related; yet they are distinct, even when equal. As an instance of their occasional inequality, we may take the case of a rigidly calcified artery, which preserves an almost constant wall-tension (after the fashion of metallic tubes), though the pressures within it may vary.

Arterial Tension distinct from Arterial Blood Pressure.—We gain a clear notion of arterial tension as an independent factor by relaxing the artery by the pressure of the finger. The blood-pressure remains, but the arterial wall is no longer tense. We have substituted for its tension that of the finger.

"High Tension" and "Sustained Tension."—Both these expressions are required for distinct conditions. Arterial tension may be momentarily high, or it may permanently remain at a high level.

In the latter case the pulse is said to possess "sustained" tension. By this, however, it is not implied that the tension is uniformly high.

"High Arterial Pressure" and "Sustained Arterial Pressure."

In connection with arterial pressures the same distinction is needed. Arterial pressure is essentially variable: hence the pulse phenomena. In all cases the maximum arterial pressure coincides with the moment of sensible pulsation; and inasmuch as it is a direct result of the cardiac systole, we may venture to call this maximum the *systolic pulse-pressure.* There are instances in which the high arterial pressure is confined to this phase of the pulse. In others, on the contrary, whilst the systolic pulse-pressure is high, there is also considerable pressure during the remaining phases: the arterial pressure is "sustained." For want of upholding this verbal distinction unnecessary confusion has sometimes complicated problems in themselves intricate.

Tension in Relation to Arterial Pressure and to Systolic Pulse-Pressure.

In man our usual means of estimating arterial pressure is the tactile impression of arterial tension. Our estimations of pressure are thus mainly inferential.

The easiest case is that in which the tension varies much. We infer from a large, tense, and hard systolic pulse-wave, followed by a small and soft condition of the artery, that a period of high pressure alternates with one of low pressure. A pulse of this kind is felt in aortic valvular regurgitation.

A much wider inference is needed in the opposite condition, in which the pulse-beat is not very large though it is hard—and the artery subsequently remains hard, and does not lose much of its volume. This is the pulse often felt in chronic renal disease. Other pulses may be large, or alternately large and small, or small, without any hardness.

The Relation between Hardness of Pulse and Arterial Elasticity.

Hardness of pulse implies the abeyance, or the absence, of elasticity. So long as elasticity has full play, a certain softness accompanies the beat, even in the presence of the stronger pressures.

The systolic pulse-pressure may be so considerable as to stretch the artery beyond the limits of elastic response. A pulse of this kind will be hard.

On the other hand, if the tone of the muscular membrane should be permanently raised, with great diminution of the arterial calibre, the elastic function will be superseded. The blood-pressure will be counteracted in this case, not by the elastic coat, but directly by the muscular.

Pulsation Restricted by Tension.

We have stated that an artery, if rigidly calcified, would resemble a metallic tube in yielding no evidence of the internal variations in pressure. A membrane stretched to distension falls into a condition distantly analogous to this. It is described as "tense," feels hard to the finger, and refuses to pulsate. The more pressure (within given limits) is made by the finger upon this tense artery, and the better will the internal variations of pressure be felt. The arterial wall is then said to have been relaxed by pressure. In other words, the tension of the finger (or of the spring of the sphygmograph) is substituted for the tension of the vessel wall. In a metal tube this result could only be obtained by cutting a window in the tube for the finger or for the button of the sphygmograph.

There are varieties of the pulse of "sustained tension" in which the size of the artery hardly varies. This is usually a pulse of moderate or of small size and of distinct hardness—possessing very little elastic reaction.

In the yielding and elastic arterial tube part of the intermittent pressure expends itself in distending the wall, which therefore oscillates visibly, and at the same time undergoes alterations of tension or hardness which the finger can recognise.

Strong oscillations in the size of the artery, within the duration of one pulsation, may also occur in pulses presenting high pressures, although this is more commonly a feature of the pulse of low pressure. In the latter there is no high tension and no sustained tension: in the former case the tension is high, although not uniformly so.

It is not therefore a theoretical refinement of analysis to distinguish two types of tense pulse: (1) The pulse of high tension with little elastic reaction (usually a pulse of moderate or small size, and of distinct hardness) (see Fig. 1); and (2) the pulse of high pressure with much elastic reaction (usually a pulse of large size, and of no hardness) (see Fig. 2). The differences between these pulses are seen to be dependent upon the functions of the arterial wall.

Summary of the Chief Combinations Influencing Arterial Tension.

(1) *High Tension with Contracted Muscularis.*—Whenever it is such as to suppress or greatly to reduce the oscillations of the pulse, arterial tension due to muscular contraction of the vessel must persist through the lowest phase of pressure as well as the highest, the slowness of contraction special to unstriped fibres not allowing any material change in the space of a single pulsation. This immovable condition, analogous to that of a metallic tube, is the extreme instance of the condition known as "sustained pulse-tension." The muscular spasm may take effect in lessening the calibre, as in the so-called "contracted tense pulse"—or it may fail to effect the reduction

FIG. 1.

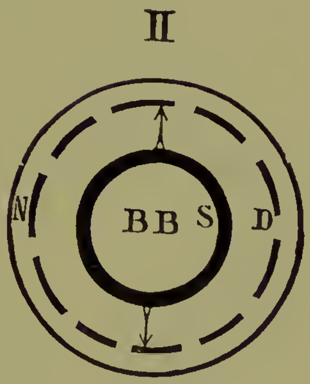

Diagram showing Arterial Diameter reduced, by muscular contraction, below the normal size (N). The lumen remains sub-normal (D), even during the pulse wave, oscillating between S and D. The blood-pressure (BB) is permanently raised.

in calibre. Muscular spasm is not therefore necessarily limited to any particular size of the artery. In the contracted pulse, the elastic reaction is kept in abeyance.

(2) *High Tension without rigid Contraction of the Muscularis.*—The same average of high blood-pressure as that capable of leading to sustained tension is, in some subjects, accompanied with notable variations in the size of the lumen. Although made slightly tense by the lower pressures, the artery allows itself in this case to be distended appreciably beyond its original size by the maximum pressures. Its walls are eminently moveable, muscular spasm is absent, and it is the elastic coat which chiefly opposes the pressures. In this condition of artery, the pulse possesses high tensions, but they are not long sustained.

Fig. 2.

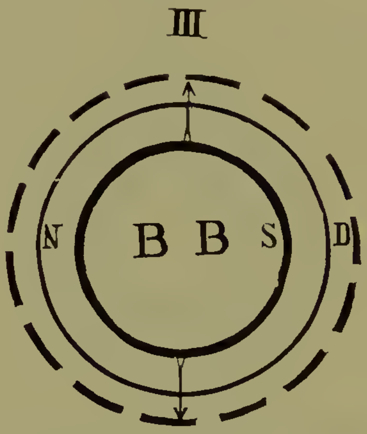

Diagram showing Arterial Diameter oscillating above and below the normal size (N). The blood-pressure (BB) is high, and overcomes, at each cardiac systole, the contraction of the muscularis.

(3) *Low Tension without Contraction of the Muscularis.*—If the minimum pressure be so slight as barely to fill the natural lumen, any rise of pressure will at first encounter little resistance on the part of the elas-

tic coat, provided no muscular rigidity should obtain. Hence low tension of pulse gives rise to large oscillations.

(4) *Low Tension with a Contracted State of the Muscularis.*—When the bulk of blood circulating through the artery is small, the arterial lumen is reduced by adaptive contraction of the muscularis, without occasioning any rise in pressure. This variety is to be distinguished from the small tense pulse previously described. A large heart-wave is not to be expected under these circumstances; and the oscillations in size of the artery would be further restricted by the contracted state of the muscularis. In extreme reduction of the volume of the blood, arterial pressure becomes inappreciable. Instances of these very small diameters remaining of subnormal size, even during the pulse-wave, so that neither the artery nor even its pulse are readily perceptible to the touch, are of constant occurrence in the so-called algid state (collapse, etc.).

It must not be forgotten that, whenever the arterial wall changes its condition, the other factors never remain unaltered. Both the blood-pressure and the ventricular contraction undergo changes concurrently.

THE MEASUREMENT OF ARTERIAL PRESSURE IN MAN BY THE SPHYGMOMETER.*

Roy and Adami insist that the diversity of the shapes taken by the tracing in the presence of high tension calls for the means of determining the pressure at any phase of the pulse-wave, but more particularly at its maximum and minimum height. Sphygmometers or pulse pressure gauges have been constructed with this view. Most of them in some way or other fail to effect the desired purpose.

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* The manometric method, represented by von Frey's tonograph, is only applicable where the artery can be exposed and opened.

The absolute arterial pressure cannot be determined accurately by Marey's sphygmograph. In von Basch's sphygmomanometer the column of mercury used for the purpose of obliterating the pulse by its pressure has the disadvantage of large inertia. Potain also obliterates the artery by graduated pressure; but, in the absence of an oscillating column of mercury, the finger placed farther down determines the moment of occlusion. This is open to the objection that the anastomotic pulse may be felt. Moreover by this method the maximum pressure in the artery is alone determined. Roy and Adami claim for their sphygmo-

FIG. 3.

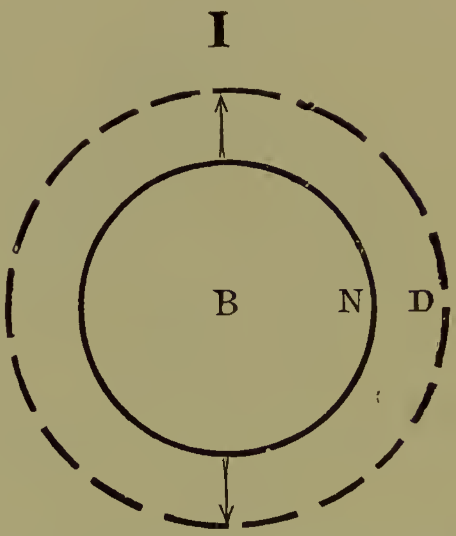

Diagram showing Arterial Diameter oscillating above the normal, or "cadaveric," size (N). The blood-pressure (B) is low, and unopposed by any muscular spasm.

meter* that it indicates with accuracy the minimum as well as the maximum pressure, "the pressures both at the bases and apices of the pulse-wave, and also with approximate accuracy the pressure at any part of the pulse-wave." The true maxima and minima would be determined strictly at the summit of the respiratory rise and at the base of the respiratory fall of arterial tension respectively.

It is found that, for each individual pulse, the maximum oscillations are obtained with a given "extra-arterial" pressure. "The height of the pulse waves, as recorded by this instrument, depends on the variations of the cubic contents of the piece of artery within the box which result from the changes in the intra-arterial pressure at each beat. They are not directly influenced, as in the plethysmograph, by the amount of blood which passes a given point of the arterial tube in a given time."† It has been shown "that the arteries of adults (in man) are relatively wider in the undistended condition—*i.e.*, when the intra and extra-vascular pressures are equal. A very slight reduction of the intra-vascular pressure, below that outside the vessel, or *vice versâ* a similar rise in the extra-vascular pressure, would produce a relatively great change in the cubic capacity of the artery. In normal conditions the pressure within the arteries never sinks below that outside their channel, and is never sub-atmospheric ; but an analogous relative effect can be produced by artificially raising the extra vascular pressure. The pulse-waves, recorded by the sphygmometer would reach their maximum size when the extra-vascular pressure reached a height just exceeding the minimum intra-vascular pressure. By means of the sphygmometer it is possible within small limits to find what is the minimum arterial pressure, as well as to determine the maximum arterial pressure.

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* For a description of the sphygmometer and for further details, see Roy and Adami, *Practitioner*, vol. xlv., p. 29.

† Roy, "Elasticity of the Arterial Wall," *Jour. Phys.*, vol. iii. 1881.

The latest observations on pulse-pressure are those of Dr. George Oliver,* made with a special pulse-pressure gauge also capable of registering the minimum as well as the maximum pressures.

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* *Practitioner* (April to August, 1893).

PART II.

THE TACTILE METHODS OF EXPLORATION OF THE PULSE.

CHAPTER I.

ANATOMICAL DETAILS IN CONNECTION WITH THE RADIAL PULSE.

The Anatomical Relations of the Radial Artery at the Wrist.

THE annexed illustrations, representing the artery in its longitudinal and its transverse sectional aspects, will render superfluous any lengthy description.

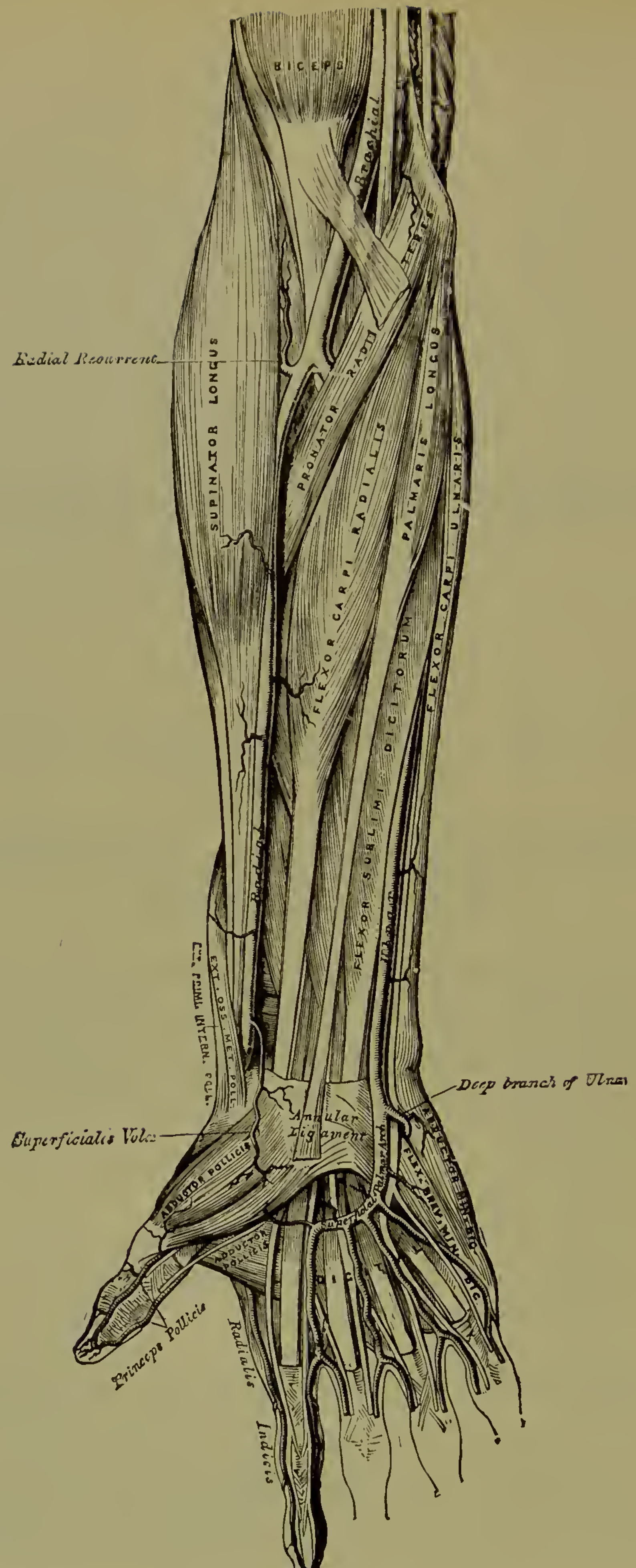
From our special point of view, practical importance attaches to its relations—

(1) to the radius;
(2) to the muscles and tendons;
(3) to the deep fascia and ligaments;
(4) to its own branches.

(1). Relations of the Radial Artery to the Radius.

At the lower extremity of the radius which rises in a prominent transverse ridge, the artery is in immediate contact with bone, ligamentous structures

Fig. 4.

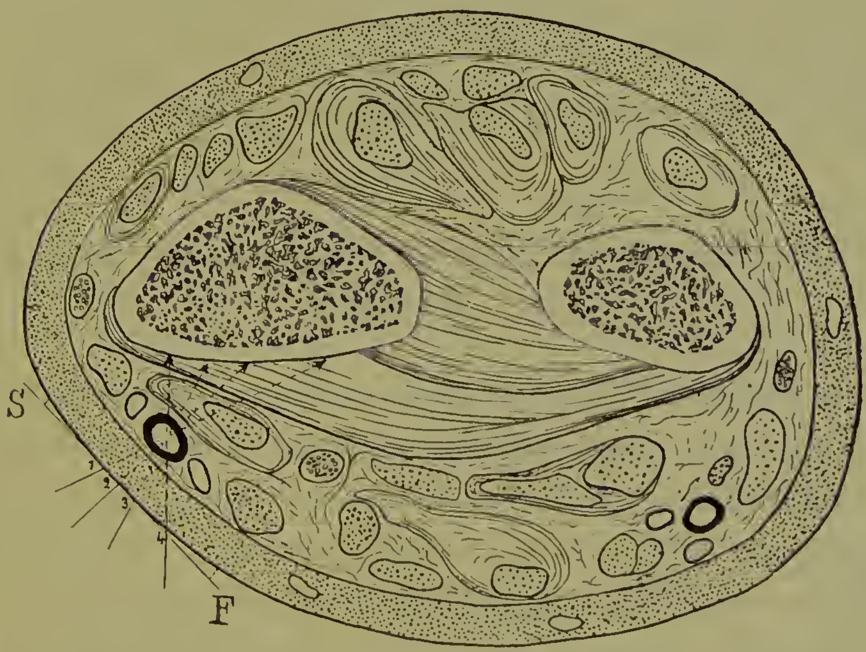


The Radial Artery and the Superficial Palmar Arch.
(From Gray's Anatomy, by permission.)

alone intervening. The vessel can be readily felt in the depression between the Flexor carpi radialis and the Styloid process, the External lateral ligament and the Extensor ossis metacarpi pollicis.

Immediately above the terminal transverse ridge from which the styloid process juts out, the anterior surface of the bone is depressed and flattened, or cupped into a shallow concavity.

FIG. 5.



The Radial Artery just above the wrist, showing its relations to the radius and to the Supinator longus (S), to the Flexor carpi radialis and to the Flexor longus pollicis. The internal S F corresponds to the usual site for palpation of the pulse, the finger being applied with various directions (1, 2, 3, 4)—most often with direction (1).—Enlarged and modified from the "Descriptive Atlas of Anatomy." (Smith, Elder & Co., London, 1880.)

A little higher up, as will be seen in the transverse section, although the radial is at no distance from the outer border of the bone, it does not lie in contact with the anterior surface of the latter. Moreover this surface slopes away from the artery, backwards and inwards. Between artery and bone the Pronator quadratus and the Flexor longus pollicis are seen to intervene. At an intermediate level, the Pronator quadratus might be the only intervening muscle.

Arrows indicate the directions in which the artery may be displaced by pressure from the finger. Pressure applied as in (4) would be resisted by a plane surface of bone. If however the pressure be made in the direction (1) it will hardly encounter any bone, and the artery will be steadied by soft parts only.

(2) Relations of the Radial Artery to the Muscles and Tendons.

The powerful tendon of the Flexor carpi radialis, standing out, with slightly oblique direction, at the anterior surface of the wrist, is an easy guide to the position of the artery, which lies at a very slight distance from it, but, having no obliquity, is seen higher up to diverge from the tendon. The tendon, separated from the artery by the inner *vena comes*, forms the inner relation. A little higher, an additional internal relation is that of the Flexor pollicis longus, which, as stated above, also lies behind the artery.

The external relations are (in addition to the external *vena comes*):

(1) The Styloid process of the radius;
(2) Below the latter, the External lateral ligament and the Extensor ossis metacarpi pollicis;
(3) Above the styloid process, the Supinator longus.

(3) Relations of the Radial Artery to the Deep Fascia and to the Ligaments.

It is unnecessary to do more than mention the deep fascia lying in front of the artery, and the anterior ligament of the wrist (fasciculus to the styloid process) behind it. Attention should, however, be drawn to the importance of the *adhesions which exist between the anterior surface of the arterial sheath and the deep fascia.* These extend along the entire superficial course of the artery, which is thus secured in a subcutaneous position and is safeguarded from encroachment on the part of surrounding structures. The artery can be dissected off the arm in connection with the fascia. It follows from this close relation that the fascia must participate to a certain extent in any movements of the artery. It is also partly owing to this close relation that the beat is visible. The cupping of the skin observed in lean subjects at the seat of diminished pulsation is due to a retreating of the artery itself. Indeed, at this spot in some wrists the prominent beat is interrupted by an interval of retractile beat, probably to be explained by the anatomical conditions.

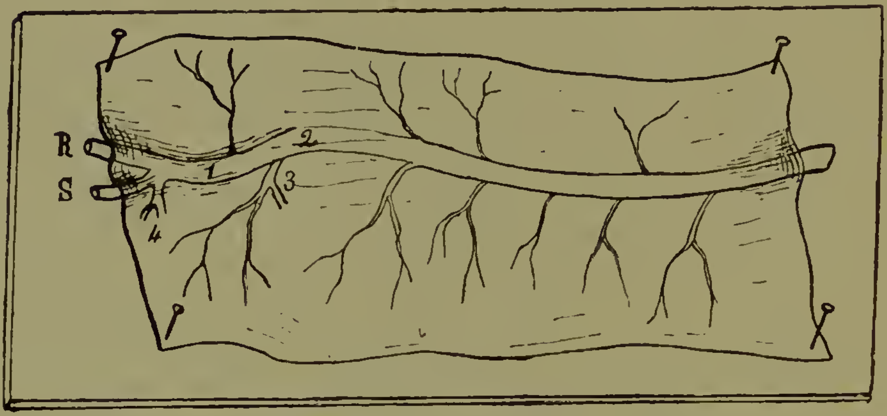
(4) Relations of the Radial Artery to its Branches at the Wrist.

Preparations were made in the manner described by removing the artery in connection with the fascia after preliminary injection. The dried specimens, being transparent, afforded an excellent view of the small branches.

Several small arteries are given off by the radial in the space of three inches of its superficial course: I have counted as many as seven arterial orifices in that portion of the bore of the vessel. They are chiefly distributed in the fascia, the four or five larger ones belonging to the ulnar side of the artery.

These vessels, with two or three exceptions, ramify in comparatively loose tissue. A small artery given off by the Superficialis volæ at its origin, and another rather larger one, usually known as the Anterior radial carpal, given off half an inch higher up, take a deep course inwards and backwards. It is from the latter that fine anastomoses are described as occurring with the anterior carpal branch of the

Fig. 6.
(Slightly reduced.)



The last three inches of the right radial artery, dissected in connection with the fascia: showing the small vessels which tend to fix the artery and to determine the direction of its curves. R. Lower end of Radial Artery, and S. Superficialis Volæ, covered by fascia and by fibres of anterior annular ligament. Terminal prominent curve at (1), partly due to bony ridge. Receding curve at (2), partly caused by deep relations of the Anterior Radial Carpal (3). At (4), artery taking a deep course in the ligaments.

ulnar artery and with recurrent branches from the deep palmar arch. Both arteries pass behind the tendon of the Flexor longus pollicis, which lies beneath that of the Flexor carpi radialis, and enter the ligamentous tissues, taking part in the supply to the joints.

Of the deep branches from the Anterior radial carpal (with which we are at present mainly concerned), some descend deeply between the fasciculi of the anterior ligament of the wrist, whilst others enter, rather higher in the wrist, into the anastomoses mentioned above. It is probably by these branches that the radial artery is tethered back almost into contact with the ligaments of the wrist.

Points of Fixation of the Radial Artery at the Wrist.

The anterior radial carpal becomes in this way a means of fixation for the vessel. Any loop produced by elongation of the artery must terminate here, and any pulsatile movement imparted to such a loop must work from this as a fixed point.

Above the receding curve which has been described, the artery rides over the flat fleshy belly of the Flexor longus pollicis, which lifts it from the bone. The fascia, to which small branches are given up in this part of the course, is much thinner and looser. The small arteries, which arise at a right angle from the ulnar side of the vessel, run a much longer course in the fascia, undivided. The freedom of movement of the radial artery is therefore much greater in that direction. On the radial side the branches are both shorter and much smaller. In this way the connections on both sides are at this level easily stretched by the ever-recurring tug of the pulse; and, under the influence of senile elongation, the vessel in this part of its course gradually acquires greater freedom of excursion and more extensive loops. The direction and curvature of the loops is doubtless governed by anatomical mechanisms as definite as those described, but these details have not been submitted to any searching study.

Probably the origins of the rather larger muscular branches supplied to the belly of the Flexor longus pollicis, about 2½ inches above the origin of the Superficialis volæ, are also points of loose fixation; and a good way higher up the muscular branches to the Flexor carpi radialis and to the Supinator longus probably exercise a similar influence.

The Curves of Elongation of the Radial Artery at the Wrist.

Arterial elongation has already been briefly dealt with from a general standpoint, on p. 39; but we are specially interested in those curves of elongation, and in those changes in their amplitude, which affect the radial artery at the wrist. Comparative observations of several elongated radials show that the changes take place, at first, according to a plan more or less uniform; although the later changes are much modified by individual peculiarities. It is best, therefore, to study this subject in the earlier phase.

In a suitable subject, lean and of middle age, an inspection of the wrist will show a beat, probably not along the whole stretch of the artery available for observation, but at certain points only. The ictus will be plainly marked for about an inch above the transverse furrow of the wrist. It will probably not be seen, or only faintly seen, higher up for a distance of one inch. Above this again, for a short distance, it will be plainly perceived.

The interval between these two stretches of visible beat corresponds to a marked backward curve in the course of the artery: the skin itself at this point is depressed, and the underlying bone presents a cupped surface. It is precisely in this situation that the fingers are usually applied to the pulse. If the finger be drawn along the artery from the hand upwards, the vessel will appear at this level to dip considerably. The thicker the styloid process of the radius, as a result of former rickets or from any other cause, the more accentuated is the depression which has been described.

Two causes influence the position of the vessel: close to the fold of the wrist, it rises over the terminal ridge of the radius; and in this situation it is firmly maintained by a reinforcement of transverse fibres strengthening the fascia which passes from the outer edge of the radius to the Flexor carpi radialis. As a result the artery is at this level almost absolutely fixed.

It is at this spot, half an inch above the fold of the wrist, that the artery is most prominent and most easily felt on superficial pressure; but also (being backed by bone) most easily obliterated by any deep pressure.

Beyond the ridge of the radius pulsation is immediately much diminished; and it disappears completely halfway between the radial ridge and the surface of the scaphoid. In this situation the point of the finger applied between the two bones will only succeed in feeling pulsation on its proximal side. The cessation of pulsation at this level is partly due to the deep course taken by the artery, and partly to its diminished size after giving off the Superficialis volæ.

The recession of the artery from the surface above the level of the ridge of the radius has its cause in the depth of the groove between the Flexor carpi radialis and the Extensor ossis metacarpi pollicis, and also in the firmness of those fibres of the deep fascia which arch across the artery in this situation on its superficial aspect.

CHAPTER II.

THE RELATIONS OF THE RADIAL ARTERY TO THE PRESSURE OF THE FINGER VARIOUSLY APPLIED TO THE PULSE.

The diagrams, 7–10, are intended to show the line in which pressure is exerted by the finger in its various modes of application, and, as far as possible, the condition of the artery under the finger applied.

A section is supposed to have been taken horizontally across the forearm, a little above the lower border of the Pronator quadratus. At the termination of the radius, the tendon of the Flexor carpi radialis exactly covers that of the Flexor longus pollicis, which is now free from muscular tissue; but at the level of the section the artery and its two attendant veins (not shown in the diagrams) are included between the fascia in front and the flat belly of the Flexor longus pollicis behind, the tendon of which is barely overlapped by that of the Flexor carpi radialis. Upwards, the latter is separated from the vessels by a small but growing interval. To the outer side of the vessels is seen the tendon of the Supinator longus, for at this level the tendons of the Extensor ossis metacarpi and Extensor primi internodii pollicis have not yet reached the outer edge of the radius, where they subsequently replace the Supinator longus tendon as an external relation.

It will be noticed that the Pronator quadratus (the thickness of which has been somewhat overstated in the drawing) underlies the Flexor longus pollicis and the artery, and that the bone is nearest to the skin at its outer border, whilst its anterior surface gradually recedes from the cutaneous surface, and therefore from the artery which remains subcutaneous.

The Four Positions of the Finger, and the Direction of Pressure in Each Case.

In all four diagrams the observer's right hand is the one employed. Two of the drawings represent the right wrist of the subject, and two the left. In the case of each wrist two modes of application of the finger are illustrated, one being intended to obliterate the arterial channel (Figs. 7 and 8), the other to feel the pulse (Figs. 9 and 10).

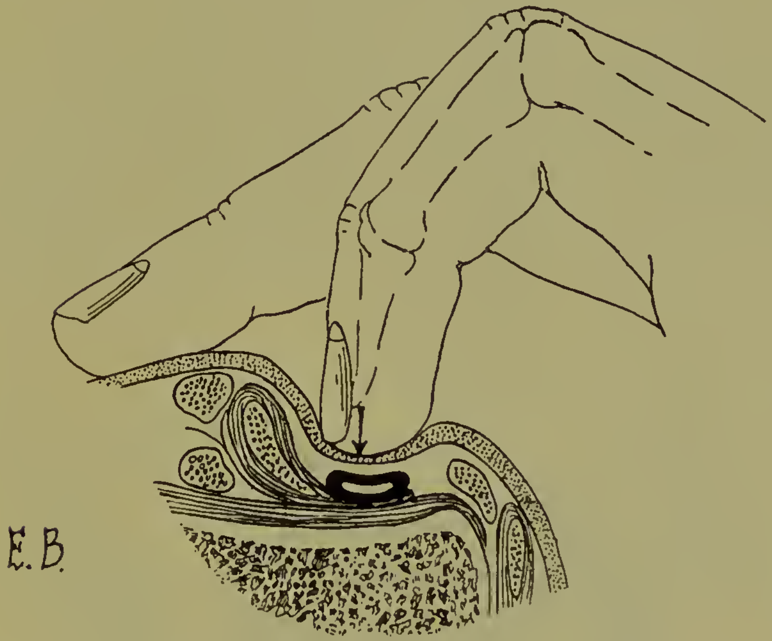
The right wrist (positions I and II) is held between the thumb applied to the back of the radius, and the forefinger applied to the pulse.

The left wrist (positions III and IV) is held in the same manner from the ulnar side, the thumb resting on the back of the ulna, the finger on the radial artery.

In each diagram the relative position of the soft parts is shown to have been more or less modified by the pressure. This will be best seen by consulting concurrently the transverse section (Fig. 5) of the forearm, taken at about the same level as the diagram; this shows the relations of parts before interference.

Two of the positions depicted are those assumed in occluding the artery, the other two in palpating it.

FIG. 7.



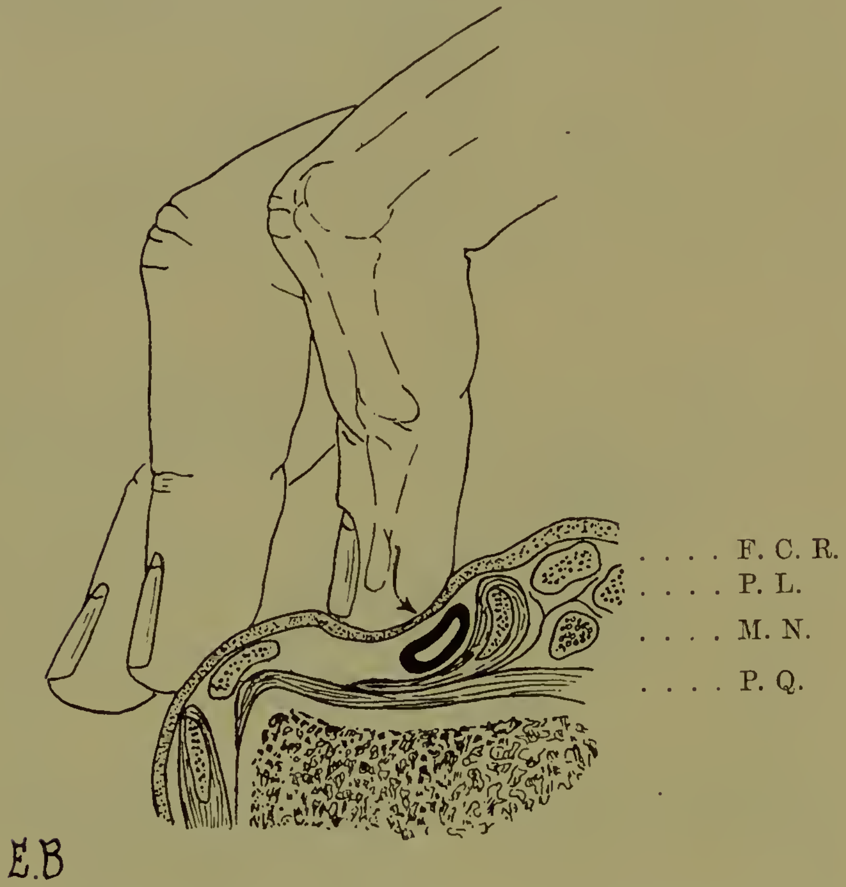
Position I.: Right hand and right wrist. The pressure on artery and bone is vertical and direct, as indicated by the arrow; it is transmitted by the phalanges (broken lines).

The Positions for Obliteration.

The most favourable arrangement for obliterating the pulse is to exert vertical pressure over the vessel near the outer border of the radius, as in position I, Fig. 7, the right hand being used for the right wrist, the left hand for the left; and the thumb supporting the wrist from behind.

It will be seen that in this case, and in this case only, the terminal surface of the finger exerting pressure, and the surface of bone making counter-pressure, are parallel. The artery is obliterated with great ease and completeness. This position is perhaps not quite so favourable for palpation of the pulse.

FIG. 8.



Position III.: Right hand and left wrist; thumb applied to the back of the ulna. Compression by the phalanx is obtained by oblique leverage against the tendons (chiefly Flexor longus pollicis). The motion is of a *digging* kind, *raising* the artery from the bone, especially when the last finger-joint is flexed, instead of extended as here depicted.

F. C. R.: Flexor carpi radialis.—P. L.: Palmaris longus. M. N.: Median Nerve.—P. Q.: Pronator Quadratus.

In position III, Fig. 8, which may also be used with a view to obliteration, the finger is applied to the opposite wrist from its ulnar side. The artery requires first to be secured by a hooking movement

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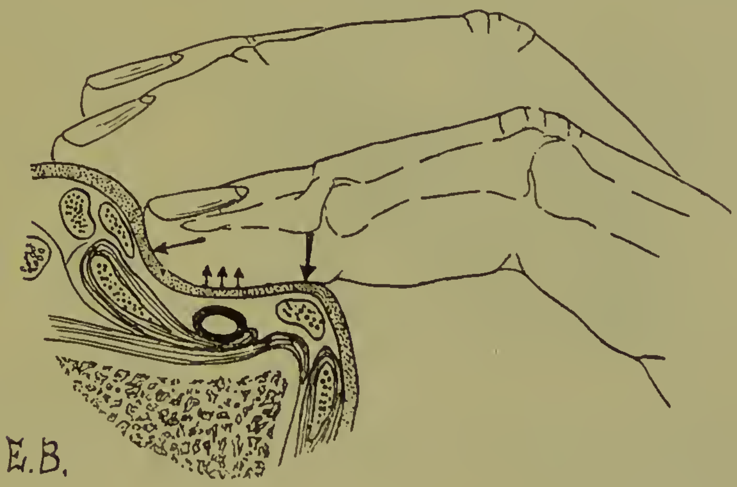
of the finger, and pressure can then be made by the phalanx in the oblique position depicted. The plane of counter-pressure is in this instance formed by the tendon and belly of the Flexor longus pollicis, backed by that of the Flexor carpi radialis. The surface of the radius near its external border is pressed by the nail; but the bone receives none of the pressure of the extremity of the finger.

For the purpose in view this is a much less satisfactory method than the previous one. For instance, in testing for the presence or absence of an anastomotic pulse, it is often found inefficient.

FIG. 9.

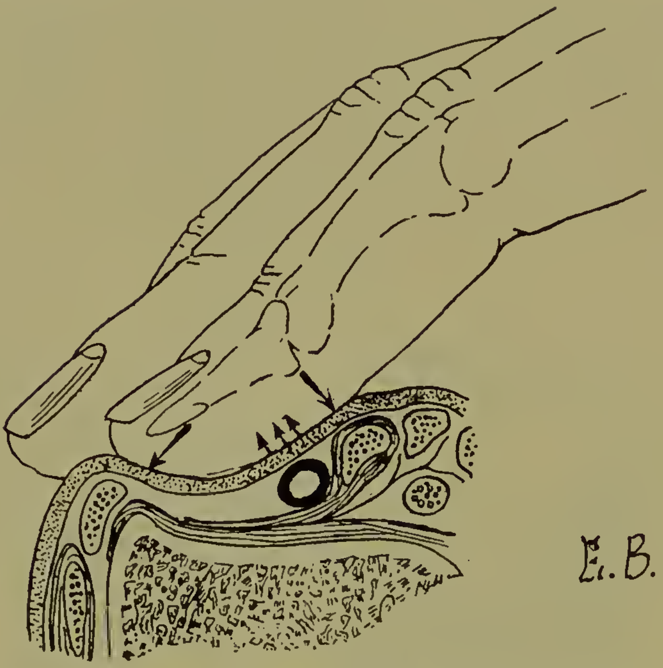


Position II.: Right hand and right wrist; thumb applied to the back of the wrist. The *strong pressures* from the phalanx (large arrows) *are withheld*, by the prominent tendons, from the artery and finger-pad; the pulse sensations (small arrows) having free scope.

The Positions for Palpation.

The principle of the method of palpation will now be easily understood by contrasting the two sets of diagrams. Both in position II and in position IV firm pressure is made; but it does not bear upon the artery. Thus in position II, Fig. 9, the finger is inclined in such a way that the extremity of the phalanx presses against the tendons of the Flexor longus pollicis and of the Flexor carpi radialis. The weight of the base of the phalanx is meanwhile supported by the prominent ridge of the edge of the Styloid process or of the radius, and by the tendons of the Extensor ossis metacarpis pollicis and Supinator longus. Over the artery itself the finger rests with very little pressure. The vessel lies as it were protected in the angle formed by the sloping anterior surface of the radius and by that of the integument, which is only slightly depressed by the finger between

FIG. 10.



Position IV.: Right hand and left wrist; the thumb resting on back of ulna. As in Fig. 9, the artery is saved from strong pressure, whilst the finger is duly steadied: fine palpation is possible.

the two points of support which have been described. The artery will hardly be perceptibly flattened, although it may undergo more or less diffused extra-arterial pressure. The correctness of the description given can be easily verified by any observer in his own person, by turning the left hand round the right wrist from underneath, and feeling the pulse from the radial side.

The conditions in arrangement IV, Fig. 10, are almost identical: the points of pressure are merely reversed. Thus the extremity of the phalanx abuts against the radius, whilst the two tendons support its base; the artery receives comparatively little of the pressure unless, as in position III, the last phalangeal joint be flexed and the vessel hooked back. Short of this, strong pressure will be difficult to apply; and most probably the artery will be pressed back, together with the soft parts, without undergoing much flattening.

In conclusion, pulsation will be easily detected in both positions (II and IV), although it may be worth noting that a slightly different portion of the pulp will be brought to bear in the two cases on the artery, that used in IV being the more sensitive. On the other hand, the obliteration of the artery is much more easily obtained in position I than in position III.

Whenever therefore the full range of pressures has to be applied in succession by the same finger, the radial pulse had better be felt from the radial side than from the ulnar side. This is also the position which will probably be spontaneously assumed by most observers.

CHAPTER III.

THE FINGER AS AN ORGAN OF TOUCH, AND THE MODE OF USING IT TO THE PULSE.

The Localisation of its Various Tactile Powers.

More study than the writer has been able to bestow on the tactile sense of the finger would probably show that tactile appreciation for various contacts is variously localised. The ordinary sense of *surface contact*, the discrimination of separate *points of contact*, the estimation of *shape*, the sense of *pressure*, etc., each seem to have their sites of tactile intensity, perhaps as much owing to the educational effect of function as to any primitive differentiation. Here are striking instances :

(1) The surface of the finger tip, just below the projection of the nail, and opposite the tip of the bony phalanx, has good discriminating power, which ceases however to be so good when heavy pressure is made. With yet higher pressures, the impaired appreciation for surface is regained, though the tactile sensation ultimately passes into that of pain.

(2) The phalangeal border, sharing much less

actively in the strong work of the hand, has delicate sensation: in spite of less refined discrimination, it retains at moderate pressures much more of it; but, with increasing pressures, it rapidly loses all tactile appreciation, and feels pain only.

(3) Again the flat of the pulp, corresponding to the centre of the papillary convolutions, would seem to be more sensitive than either, both for fine contact and for pain. Very moderate pressure is the most favourable condition for its use in palpation.

Further analytical study of this portion of our subject is indicated. For the present purpose it is enough to have drawn attention to the special aptness of the two last-named regions for fine palpation, and to the relative inefficiency of the extremity of the finger.

The Tactile Functions of the Finger in Relation to the Pulse.

The functions of touch lie in two directions: (1) the reception of impressions; (2) their analysis.

(1) *Individual Tactile Impressions*, now as of old, vary with the skill and the care of the observer. Those usually recorded are of a general order: they relate to the suddenness, duration, hardness or softness of the pulse, to its tension and compressibility, and to other characters. From none of these do we gather any information touching the cause of pulsation, or its mechanism.

Among tactile impressions there are others, however, of a more complex kind, by which we might be enabled to form some notion of the shape of the pulse. Putting aside the earlier work of the Chinese in this direction, Fouquet's work stands by itself as an endeavour, anterior to the sphygmograph, to analyse some of these sensations and to express their form graphically. His organic theory of the pulse cannot be upheld, but the accuracy of some of his personal observations may be tested by any one of us.

(2) *Their Analysis*: We may regard the finger as an instrument of analysis, and its pulse-sensations as the material to be analysed. Fouquet's observations, lacking the help subsequently given by the sphygmograph, did not carry him much farther than the recognition of distinct forms of pulse-waves, each of which was considered as a whole. The peculiarities which he noticed in each were not made by him the subject of methodical analysis, much less of experiment. This part of the work remains to be accomplished.

The Scope of Tactile Analysis.

The analytical study of the pulse is based upon observations of shape, of time, and of pressure. The idea of shape is conveyed to the mind without any activity on its part as a ready-made impression, but analysis will add much more definition to this first impression. A study of the variations in the shape of the pulse-wave under heavy pressure, under light pressure, and in the absence of pressure, is part of this analysis. Again the results of each degree of pressure are capable of being considered in a threefold relation: (i) as to locality; (ii) as to time; (iii) as to duration.

Judgments as to pulse-pressure are rather within the competence of muscular sense than of touch itself. At any rate tactile impressions are very misleading in this respect. Dr. Oliver mentions, as a result of experiment, that muscular sense as represented in the finger, is unequal to the task of estimating pressure. Nevertheless, in this as in other directions, latent aptitudes need education and probably will respond to it. It seems not unlikely that it may be easier to learn to estimate the degree of the pressures exerted than of those resisted by the finger.

THE METHOD OF PALPATION.

The importance of a uniform method cannot be fully understood until we have shown to what extent various manipulations modify the pulse, causing a difference not alone in the sensations of the observer, but in their subject matter. Still it must be obvious that if different observers were to realise different sensations, they would be at a disadvantage when attempting, in the absence of any common ground of analysis, to discuss together the tangible characters of any pulse. Certain it is that in each of us the sensations vary appreciably according as we use one, two, or three fingers at a time. This alone would show the need of some uniformity in the method of observing, which might enable observers to perceive almost identical sensations from one and the same pulse.

Of the Various Modes of Feeling the Pulse.

The detail of all the methods advocated at different times would be wearisome. For each of them something may be said; and, so long as only a general impression as to pulse-strength and volume is sought, any of them may answer. Inferior weapons skilfully handled often do good service; but for the analytical study of the pulse there is but one available method, which will be described later.

Reasons will be given for holding the radial side of the wrist in preference to the ulnar. As regards fingers, the adoption of the old Galenic position or the reverse (viz., of the index placed nearest to the wrist, or farthest from the wrist) is without practical importance, although we must not forget that the sensitiveness of the ulnar and of the radial side of the fingers differs.

It is interesting to note that the ancient seals of the Royal College of Physicians of London show the hands in both positions in different instances.

In connection with the varieties of palpation, Floyer says:* "The Fingers may either compress the Artery much, or touch it lightly, or be applied in a moderate way, with a moderate compression, according as the strength of the Pulse is; for a weak Pulse is stopped by a great compression.

"The feeling of the Pulse in Fat People is very difficult, but it appears most evidently betwixt the Hand and Wrist.

"In the feeling of the Pulse we must bend the Hand towards the Wrist, that the Artery may be a little relaxed and better distended by each stroke; and in weak Pulses we must turn the

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* *Loc. cit.*, pp. 154, 155.

Wrist downwards, or in such Posture as the Artery may best approach to the Fingers freely."

Again (p. 228): "The Chinese hold the Pulse sometimes the Right, sometimes the Left, and sometimes both; they lay their four fingers along the Artery, and when they have pressed the Artery strongly, and by degrees, they raise them again by degrees, till the blood recover its Course; then they press the Arm again, and hold it a considerable time till they discern all the Disorders of the Pulse, and then they tell the Disease."

What has been said (p. 46) concerning the varieties of small pulse suggests a general method to be adopted in feeling the pulse when of small size. In all cases of this kind it is necessary to use in succession: (1) Firm pressure which may relax the arterial wall if tense and allow pulsation to be made out. (2) The lightest possible pressure; this will often enable us to perceive pulsation where, under a less delicate touch, the imperfectly filled artery might appear to be pulseless.

How Many Fingers should be Used?

In feeling any solid object we use many fingers. It has been argued that we should do the same in feeling the pulse. It is true that if the arterial walls are the object for palpation we can hardly use too many fingers at a time; but we might use too many in studying the pulse-wave. Were the pulse-wave of smaller size than the digital surface used for palpation, its passage might be best studied by multiplying the stations for watching the transit. It is however of unmeasured length. If we wish only for an increased surface of contact with it, why not use the length of a single finger instead of endeavouring as it were to join three finger tips into one? Tightly pressed together, the fingers, it is true, lose much of their individuality; but some of the objections remain, which will be pointed out in the sequel.

Since the power of touch varies at separate spots on the same finger, it cannot be indifferent whether the two inches of artery subjected to palpation be covered by the tips of three fingers, or by the flat of a single one.

In using the tips of several fingers as opposed to the flat of one finger, it must be remembered that each finger has its own separate gradations of sensitiveness, and is also apt to exercise independently its own gradations of pressure. (*a*) When the fingers are pressed close to one another, the difference between them is reduced to a minimum; (*b*) when they are separated, the difference is much exaggerated, as will be seen hereafter; (*c*) in using the flat of one finger, although tactile appreciation may vary from spot to spot even more than at the tip, still the sensations themselves are continuous and therefore more easily interpreted.

Feeling the Pulse with a Single Finger.

In conclusion the use of one finger commends itself to us for the same reasons as it did to Floyer (*loc. cit.*, pp. 154, 155):

> "The Old Direction was to apply three Fingers to the Arms, or two, but I think one is more discerning, and less apt to impose on us, because the feeling with three Fingers may give us a false Notion of that we feel; and since the Artery is now known to move in all parts at once, for at the same time the Heart constringes itself and strikes the Ribs, we discern the Pulse in the

Artery, as, if a Solid Body were moved at one end, it moves in the same time at the other; so it is in the Artery when 'tis filled with blood; and since we can touch but a small part of the Artery, we cannot discern the Celerity of the Motion of the Blood, as it passes from one part of the Artery to the other, but our Reason infers it from the Celerity of the Arteries impression on our Fingers. I generally feel my Artery by my Thumb, and the reason of prescribing many Fingers was the Opinion of the Artery moving itself differently in different parts."

Being more detached, the thumb gets at the pulse better than any other finger, and lends itself to more extensive manipulations. It can be made to feel with its entire length, whether on the flat or along its border; and it can bear pressure with its extremity, or with the flat of the pulp, or with any parts of its palmar surface in succession. For a general estimate of the conditions of the pulse, of the pulse-wave, and of the artery at one time, it is not surpassed; but it fails in the work of fine analysis.

The reasons which make us prefer the length of one finger to the tips of several are yet more strongly in favour of the use of *a single finger tip*. If only there is sufficient tactile power in the end of one finger, the unity of sensation thus gained is a primary and all-important advantage for tactile analysis.

CHAPTER IV.

ELEMENTARY TACTILE OBSERVATIONS.

I. THE TACTILE EVENTS IN THE PULSE.

The Beat and the Pause.

THE finger placed in a suitable fashion over the radial artery feels a succession of beats equally resembling each other, and normally recurring at absolutely regular intervals. The endless repetition of the beat furnishes us with every opportunity of studying the phenomenon ; and its rhythmic character is, as we shall see, of practical assistance in our observations.

The recurring *beats*, and the regularity of the interval or *pause* which separates them, constitute the simplest of all tactile observations. The pause exists in our sensations rather than in the pulse itself. The pulse is practically never at rest. The length of the "so-called" pause is really the measure of our own lapse of attention or of the inadequacy of our observation. There is no real pause in normal pulses, since one pulse-wave does not terminate till the ensuing one is about to begin.

The ancient terms arterial systole and diastole have wisely been given up, although not open to any reproach beyond that of almost inevitable confusion. Arterial diastole or expansion (corresponding to the ventricular systole) is a period of definite intra-arterial change. Arterial systole, or contraction (corresponding to the ventricular diastole), is another period of arterial movement, albeit of a different order.

The Rise or Upstroke; the Beat or Ictus; and the Fall or Subsidence of the Pulse.

In one important respect the expressions systole and diastole implied error; the diastole or dilatation was supposed by Galen and his followers to be, as well as the systole, a spontaneous effort of the artery, an active movement of the arterial wall, instead of a passive stretching by the pulse-wave. Systole and diastole were correct expressions as defining periods, rather than moments, of time. The same idea of duration is contained in the expression pulse-wave, which refers to a demonstrable reality. In this, as in any other wave, we distinguish a rise, a summit, and a fall.

In order that the artery should be perceptible to the touch, its hardness or tension must exceed that of the surrounding tissues upon which the finger is making pressure. This is the case during the rise of the wave, and especially at the moment of the beat. The arterial tension during the fall of the wave may not in all cases be sufficient to be felt; most commonly it is.

I. The Pulse-Sensations Corresponding to the Rise of the Wave.

The Rise or Upstroke is much quicker than the fall. Its rapidity has often caused it to be overlooked. Indeed, though aware of its occurrence, we may fail to notice it unless the whole attention be given to its perception. The finger, if light enough, should feel every part of the rise, which appeals both to the sense of pressure and to that of touch.

It will be noted that by alternately using one finger or two, to the same pulse, the act of expansion of the artery prior to the ictus will appear to last a shorter or a longer time.

II. The Pulse-Sensations Corresponding to the Beat or Ictus.

The Acme or Beat.—The feeling imparted to the finger is quite different from that suggested by the pulse-tracing, for reasons which cannot be set forth briefly.

The ictus is perceived as a rapid *round shot*, or as a quickly passing *oval slug*, or as a long, moving *bolt*, according as the pulse is tested with a mere point of the finger pulp, by the whole pulp, or by the pulp of two or more fingers.

This is another demonstration of the fact that the mind and the finger both have a great deal to do with the feel of the pulse.

The ictus is the central tactile event in the pulse. At the same time it is the one visible *par excellence*. Although a product of the pulse-wave, and coinciding with part of the wave, it is essentially distinct from it. Its mechanism will be discussed later.

III. The Pulse-Sensations Corresponding to the Fall of the Wave.

To follow the retraction of the artery requires great attention, a delicate touch, and a progressive pressure from the finger. For this special purpose three fingers are, as an exceptional case, better than one ; the impressions, being feeble, gather distinctness from their repetition. It may thus be possible to follow the falling wave, if large, almost to its end. Usually one half only of the fall will be distinctly felt. The *dicrotic* or *secondary* wave if fairly marked will not escape the careful observer ; if fully developed, it is obvious. The tertiary waves cannot be distinctly felt unless unusually prominent.

The descent of the wave and the dicrotic event are sometimes visible, as well as to be felt, in rather thin subjects with prominent arteries. A marked dicrotism is a help in identifying the descent of the pulse, affording as it were a landmark for the eye. It is often present in pulses whose suddenness and elasticity favour a recognition of the final stages of the waves whilst giving peculiar prominence to the ictus.

II. THE TACTILE EXPLORATION OF THE ARTERIAL WALL.

The artery is to be emptied by the pressure of two or three fingers, whilst one of them performs careful palpation, both along and across it. A sound artery may be flattened without conveying a feeling of hardness. In children and in youths, especially when well-nourished, the vessel may be even difficult to identify, being lost to the touch among the other soft parts. With increasing thickness of wall, the flattened artery will give the same feeling as a thick ribbon or as a thin indiarubber tube. A contracted artery yields the characteristic impression of cylindrical shape. If atheromatous, the artery will feel much firmer and thicker; and if calcified, it will remain hard and rigid in spite of the pressure. Highly calcified arteries often feel ribbed like ipecacuanha-root. In all these cases the artery can be more or less easily rolled under the finger. Elongated arteries bent into curves are almost invariably thickened, elongation being the result of high pressures and of large pulse-waves continued for long periods. The passage of the pulse-wave jerks the elongated artery, accentuating or smoothing some of its curves (locomotor pulse.)

The State of the Arterial Wall as Gauged by Tactile Impressions.

(1) A large and soft pulse, without abruptness or sustained tension, suggests a relaxed state of the muscular coat. A ready dilatation and a ready recoil are both evidence of a full elasticity, unhampered by any muscular rigidity.

(2) A rather large and strong pulse, heaving as well as tense, indicates a powerful cardiac systole and a powerful resistance, which largely resides in the

capillaries, but slightly also in the muscular coat stretched by the volume of blood, whilst its fibres are partly contracted.

(3) A small and tense pulse indicates muscular contraction of the vessel; but of this it is difficult for the finger to gauge the degree. A contracted artery being smaller and its walls therefore thick, these will not be readily stretched by the systole, but will offer to it an active resistance, a given strength of heart contraction producing a comparatively slight rise of the pulse.

Thus an elastic artery possessing, before the occurrence of the pulse-wave, precisely normal size, will give a maximum size under the influence of the cardiac systole. But if previously in a state of muscular spasm it will perform a smaller pulse excursion.

It may thus come to pass that as in Diagram ii, Fig. 1, even the pulse-wave may not dilate the artery to the size it should have possessed when at rest or in the cadaveric state.

The Tactile Signs of High Tension.

A determination of the presence or absence of tension is one of the chief objects in feeling the pulse. Most observers consider themselves equal to its due performance. Yet according to Dr. Oliver the tactile discrimination possessed by the finger for pressure is very small, in comparison with the instrumental tests for it. It is probable, however, that the finger can do better when placed under circumstances with which it is familiar than in a novel experiment.

It is certain from the experience of those employed in testing the weight of coins, that much can be achieved by education in training the power in question.

Let us remember that the tactile tests usually applied are not direct. We do not estimate the amount of pressure so much as the results to which it leads in connection with the artery, and in connection with the pulse-wave. (*a*) The walls of a permanently tense artery are non-collapsing: instead of vanishing, they are felt between successive beats. (*b*) Blood-pressure, which sets up tension in an artery, also resists compression; and when it is considerable a greater weight must be employed to effect arterial obliteration. (*c*) Whilst the radial artery is thus obliterated by pressure, should a finger be placed over its course a little lower down, a regular pulsation may be felt in it, as though no compression were being made: this additional pulse (conveyed through the palmar arch from the ulnar artery), not being constant, is not a distinctive feature: it occurs also in pulses in which the tension is low. It cannot, therefore, be used as a test for high tension.

PART III.

THE RUDIMENTS OF TACTILE ANALYSIS OF THE PULSE.

CHAPTER I.

PRELIMINARY EXPLANATIONS.

I. THE DIAGRAMS REPRESENTING THE ARTERY AND THE FINGERS APPLIED TO IT.

THE simple diagrams which illustrate the sensations described are made up of two elements: the artery in its longitudinal section, and the terminal joint of the finger variously applied.

The Artery.—The obvious disproportion between the arterial diameter and that of the finger is intentional, affording room for a clearer representation of the intra-arterial events.

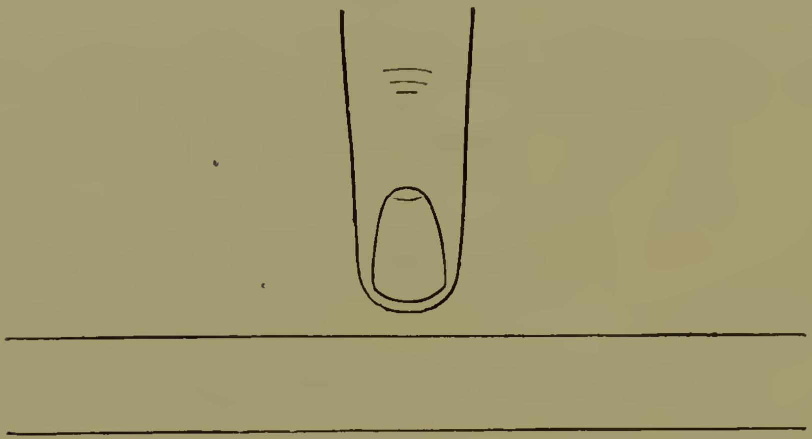
The Fingers.—The following notations will identify the relative position of each of the fingers at different points in the course of the artery:—

Cf : *the central finger* (*nearest the heart*),
Mf : *the intermediate finger*,
Df : *the distal finger* (*nearest the hand*).

The letters *C* and *D*, placed near the fingers, point respectively to their *proximal* (or central) and to their *distal* side.

The Arrows.—Minute arrows indicate on the finger the direction of the sensation, whether axial or oblique. Arrows placed *beneath the artery* give in each case the direction of the systolic pulse-wave, or of the blood stream. Longitudinal arrows placed *within the artery* have various shapes and sizes. They refer to intra-arterial events, their special meaning, in each instance, being sufficiently explained in the text.

FIG. 11.



The artery in longitudinal section and the observer's finger.

Thick Arrow-heads within the artery, or immediately above it, are used as symbols for the "beat" or "*ictus*." *Groups of three* arrow-heads also occur (with the same meaning) beneath the tip of the finger, the lateral arrows sometimes rising into an arch, as a symbol of the sensation which accompanies the beat. Whenever the large arrow-head is used in duplicate, inside and outside the artery, in connection with one and the same ictus, special mention will be made of the fact.

N.B.—The minute arrows on the fingers are almost invariably mere duplicates of symbols occurring within the lines representing the artery. To this point we need not again refer.

II. Note on the Perception and Appreciation of Minute Intervals of Time between Impressions.

Tactile Test of Priority between Overlapping Sensations.

Even in the normal pulse the rhythmic events are rapid. In the frequent pulse, their timing becomes an arduous matter. The question usually takes this form: of two events, almost, but manifestly not quite, synchronous, which is the earlier?

The difficult estimation of priority between the overlapping tactile events may be facilitated in the following way: Let us take as an instance the progress of the pulse-wave along the arm. Two fingers of the same hand are applied, we shall suppose, to the radial artery at *A* and *B*, points on the fore-arm two or three inches apart. So brief are the time intervals of the passage of any pulse-event between these points, and such is the influence of mental convergence on sensorial estimates, that, according as we turn our attention more to the one or to the other finger, each may seem in turn to be the seat of the earlier event. We will suppose that the events are not absolutely synchronous, but that *A is a little earlier* than *B*. The tactile proof of priority will be that, if the mind be first made intent on *A*, the occurrence at *B* will now be felt as *a second event;* whereas if attention be so strongly turned to *B* that the event wrongly appears to begin there, *it will be impossible any longer to catch a separate impression at A.*

The Acoustic Time-Marking Method for the Accurate Registration of Rhythmic Events.

Martius remarks that experimental proof has been arrived at, in spite of Hermann's statement to the contrary, that for the registration by the observer himself, of the time of rhythmic stimuli, the absolute duration of the interval between the stimulus and its registration (putting aside minor experimental errors positive or negative) is *nil.* This has been experimentally proved by Byrom Bramwell and R. Milne Murray, and by von Ziemssen and von Maximowitsch.

Byrom Bramwell* describes the principle of his method in the following words:

> "If the levers of two Cardiographs (one worked by the apex-beat, the other by the forefinger of the auscultator) were so adapted as to move in exactly the same vertical plane, the exact time-relationship of the sound or murmur to the ventricular systole (or other phase of the cardiographic trace) could be determined, provided that the 'Psychical loss' previously alluded to,

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* Byrom Bramwell and R. Milne Murray, "A Method of Graphically Recording the Exact Time-Relations of Cardiac Sounds and Murmurs," (*Brit. Med. Jour.*, Jan. 7, 1888).

were accurately measured[*] and deducted." It is found, however, that "under the conditions of the experiment[†] there is absolutely no 'psychical loss.'"

The Psychical Delay in Observations Made with the Ear and with the Eye Respectively.

It is often convenient and sometimes necessary to combine visual and auditory observations, as for instance when listening to the heart-beat and watching the visible pulse of an artery. Thus the question arises whether visual and auditory stimuli produced simultaneously are, or not, simultaneously perceived in the sensorium. According to Exner the interval is not the same in both cases: the difference, which averages between ·04 and ·06 of a second, being due to the relative delay in the perception of the visual stimulus.

From this it follows that when the heart-beat is watched with the eye its occurrence should be antedated, or reckoned back, ·04 to ·06 of a second from the moment observed.

If on the contrary the acoustic method be used, the error is a much smaller one: it will amount at most to ·03 of a second, and it may be an error on one side or on the other—*i.e.* either in advance of, or behind, the real time.

It is interesting to find that Marey ("La Circulation du Sang," p. 127) employed this method for the registration of the heart-sounds. The exact method consisted in beating the india-rubber tympanum of a time recorder. Edgren and Martius independently adopted the same method some years later; but Martius' determinations were limited to one of the two sounds.

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[*] On a simultaneous time record.

[†] A clock had been put into circuit with the telephone and its recording lever, by which "make" and "break" sounds rapidly following one another were made every second.

CHAPTER II.

I. ON THE VARIETY OF INDIVIDUAL TACTILE PERCEPTIONS, AND OF INDIVIDUAL JUDGMENTS, AS TO THE SHAPE OF THE PULSE.

JUDGING from the variety of his own sensations under successive examinations by a series of observers, a patient might rightly infer that their individual sensations had differed no less than his own. The variety of sensations to be obtained by a single finger (and much more by two) when applied to any pulse in different ways, is a fact leading to a similar conclusion.

The wonder is that examinations differing so much among themselves, and deficient in analysis, should enable each observer to frame apparently definite conclusions as to the things felt. If definite mental images were arrived at in each case—and this may be doubted—they would probably present considerable variety.

This point could only be tested by obtaining from each observer a facsimile sketch of his tactile impressions. Of these sketches enough have been collected by the author to demonstrate that the mental pictures evolved from pulse sensations are very different for various observers; and that, in the case of the medically trained, pulse perceptions, or at any rate pulse representations, are strongly biased by reminiscences of the sphygmogram. In contrast with all such, Fouquet's diagrams, free from any influence of this kind, possess singular value.

II. The Author's Pulse-Sensations, at an Early Stage of Study; and His Mental Picture of the Pulse at that Stage.

The annexed diagram is of some interest, as identifying an intermediate stage in the evolution of ideas on the pulse, a stage now difficult to recall to mind, since further analysis has changed the entire aspect of things. It may also be of use in contrast with subsequent descriptions and graphic illustrations of the sensations experienced when feeling normal pulses.

The study upon which the diagram is based was made by the author with two or three fingers, on his own pulse: this specification is the more necessary as, at this stage of the inquiry, it would be inadvisable to draw general inferences from personal sensations, however definite and constant in their recurrence, especially when the sensations had been chiefly obtained from an individual pulse.* For graphic purposes the tracing has been doubled, as though the artery were felt from both sides instead of from one surface alone.

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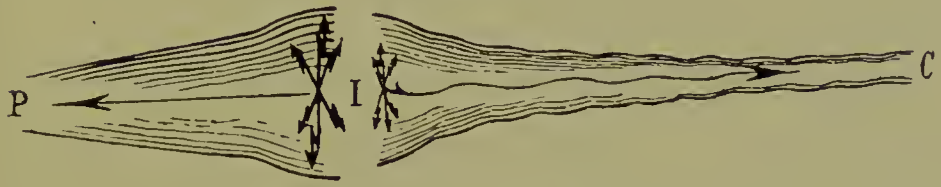
* It is right to state that the same sensations were looked for and obtained from the pulses of other subjects.

(I) The earliest sensation, corresponding to the *beginning of the wave*, is a little indefinite; but the feeling of the finger being lifted grows rapidly, and becomes substantial. The wave is felt by the fingers to be moving onwards the periphery P.

FIG. 12.



The author's first graphic representation of the normal pulse, felt with three fingers. P: The head of the wave moving towards the hand. I: The brief eclipse of the wave, immediately after the ictus. C: The tail of the wave, seeming to move towards the heart.

(II) The next phase is that of the *ictus*. There are two changes perceived at this stage: (1) A marked *increase in the volume* of the artery. This increase is sudden; its amount varies with the pressure which is at the time being made on the vessel. (2) The ictus or beat almost conveys to the finger the idea of *an explosion*. The same idea is rendered by the old term *micatio* or *fulguratio*; and it is roughly expressed in the diagram by the forked arrows.

Another simile expressing the feeling perceived is that of the blow dealt with the heavy long hammer. That part of the wave which forms a prelude to the ictus is represented by the hammersman's heave immediately preceding the blow.

The moment of the beat appears too short for any definite estimate of direction. The impulse seems to be, so to speak, stationary, and limited to one spot.

(III) After the ictus, follows a brief *interruption;* or rather an impression that the wave is interrupted.

(IV) When perceived again, beyond the interruption, the size, the strength, and the distinctness of the wave are much diminished. It may even be difficult to feel the wave at all.

The reduction in size is very marked. As shown in the diagram, the return of tactile sensation may be heralded by a sudden, but feeble, explosive event, suggesting the idea of a faint echo of the ictus, and, at the same time, the volume may be less reduced than it is immediately afterwards. The remainder of the wave gives a very feeble sensation, though one very characteristic. In the first place it possesses an *undulating surface* which gradually falls to lower and lower levels, until it is lost to the finger; and in the second place its direction seems to be *centripetal.* The sensation of the artery slowly emptying its contents in an upward direction, whilst the impression of the downward rush of the head of the wave still occupies the mind, is, after the ictus itself, the most remarkable among the feelings perceived with three fingers on the pulse.

Later results, whilst in great measure confirming the correctness of these early observations, will show that their interpretation was at fault. The impressions detailed were essentially composite, and therefore not faithful representations of the pulse-wave; each of the three fingers receiving successive sensations, whilst from the latter a single image was evolved.

CHAPTER III.

THE TACTILE EXPLORATION OF THE PULSE-WAVE.

The Multiple Impressions reaching the Finger.

THE tactile analysis of the pulse has two aspects: the study of the feelings conveyed to the finger—and the study of the changes induced, by the application of the finger, in the artery and in the pulse-wave. As far as they will admit of a separate consideration, we purpose to deal in succession with these two lines of inquiry; and we shall begin with the first.

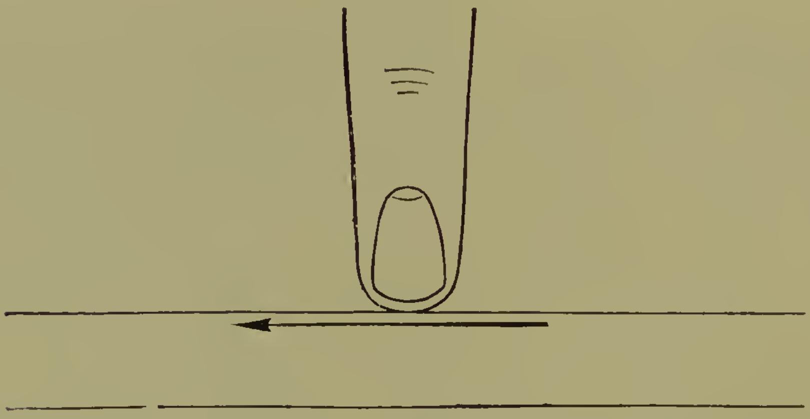
Although the sensations of a single finger applied to the pulse will become very definite when they have been analysed in the following pages, usually they do not satisfy the observer: he proceeds to use two or more fingers. Yet his real difficulty lay in the variety of sensations conveyed even to one finger. When more fingers are added, there is a growing complexity of impressions, and a worse confusion among elements which should be kept distinct. Still there is satisfaction in the consciousness that the pulse is now "adequately handled." And somehow from this mixture of sensations, each observer learns to extract his own practical estimate of the individual pulse, easier to conceive than to express.

The Graduated Application of Pressure.

Probably the most important differences between the methods personal to each lie in the management of finger-pressure. Such, at least, is the impression gathered when one's own wrist passes through a succession of hands for examination.

It is well known that the sensation of the finger will vary with the amount of pressure exerted by it; but there is still wanting a systematic analysis of these varying sensations.

FIG. 13.



Pressure I: Very light, almost of simple contact. The pulse wave passes under the finger undiminished.

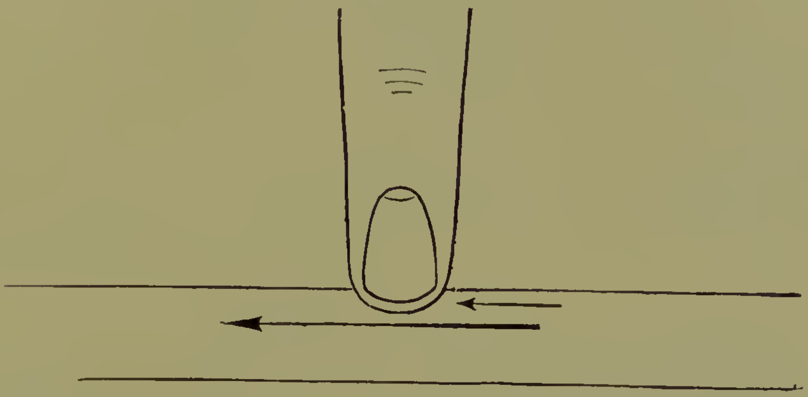
Diagrams may add clearness to the differences under consideration; but we should remember that the classification of finger-pressure which they represent is arbitrary, and merely subservient to the purposes of study.

(1) The application of the finger may be so gentle

as to leave the arterial surface unaltered in its curvature.

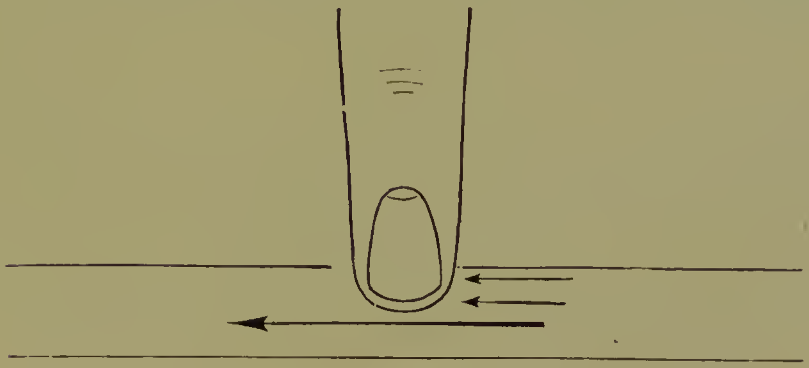
(2) As light depression of the arterial surface by the finger is the next step. We shall suppose that the diameter of the artery is reduced by *not more than one-fourth* at this stage.

FIG. 14.



Pressure II: Light (¼). The greater part of the wave travels onwards beyond the finger.

FIG. 15.



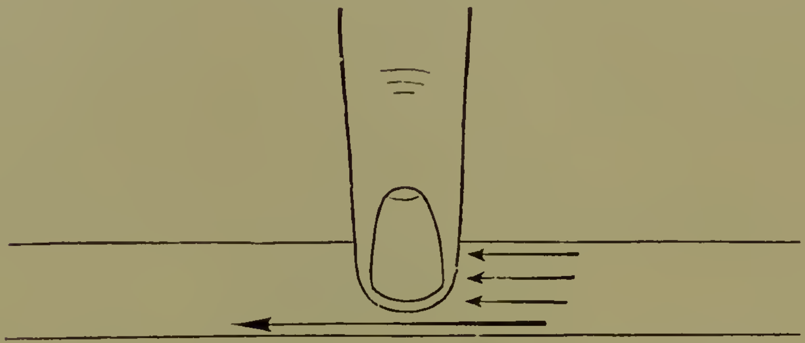
Pressure III: Moderate or intermediate (½). A good portion of the wave passes on.

(3) Additional pressure will materially lessen the patency of the vessel. So long as the reduction, although greater than one-fourth, *does not exceed*

half the original diameter, we shall speak of the pressure as *intermediate.*

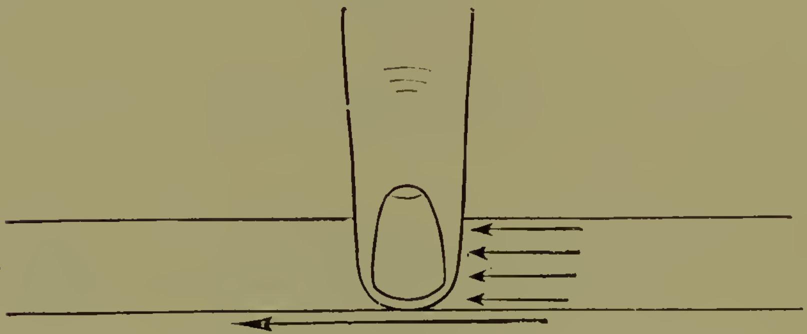
(4) Stronger pressure increases the obstruction, so that a quarter only of the original channel remains. The arterial stream, though much contracted, continues to flow, but the pulse-wave is so much reduced as to be imperceptible, in the majority of cases, beyond the finger.

Fig. 16.



Pressure IV: Stronger ($\frac{3}{4}$). What portion of the wave may pass, escapes recognition by the finger.

Fig. 17.



Pressure V: Strong. The arterial lumen is obliterated.

(5) Henceforth it matters little how much pressure is used. The object being complete obliteration, the observer commonly makes sure of the result by employing much more force than is needed.

Since they will frequently be referred to we may conveniently tabulate the pressures as follows:

Pressure i: *Very light* (*almost of simple contact*);
Pressure ii: *Light* (*about* ¼ *diameter*);
Pressure iii: *Moderate* (*about* ½ *diameter*);
Pressure iv: *Stronger* (*about* ¾ *diameter*);
Pressure v: *Strong* (*complete obliteration*).

One of our main objects in pulse-analysis will be to use separately each degree of pressure, and attentively to watch its effects.

The Tactile Events in the Pulse-Wave.

The sphygmograph has greatly advanced tactile analysis by showing us what to observe. We have learnt to feel, and, in suitable cases, even to see, almost the entire pulse-wave; and we can now give a more detailed answer to the question, "What is the pulse?"

Something more than a beat and a pause can be made out in any healthy pulse. The general feeling obtained when one finger is applied to the pulse is one of upheaval; but, with due attention, this feeling will be felt to resolve itself into three phases: (1) *a rise;* (2) *a beat or ictus;* and (3) *a recession.*

(1) *The rise* is of short duration, but definitely perceptible as an event. The finger seems to be rapidly, yet gradually, lifted from a dead level, as though a wedge had been quickly slipped under it. If two fingers be used side by side, the rise will be much more appreciable.

(2) *The Ictus.*—This is the central and most

tangible event in the pulsation. Indeed, it is generally the only phase described; and it is probably the only one perceived by most. Its onset is so sudden, it works up so quickly to an acme, after which it so instantly vanishes, that the old name *micatio* or fulguration is strictly appropriate. We are reminded of the explosion of a rocket which fills the air for a brief period and is gone; something so real whilst it lasted, which is no less startling in its disappearance: we are left in suspense, and as it were in touch with nothing. The word ictus or blow conveys some of this meaning. So thoroughly does this event dwarf the rest that nothing may be felt beyond a series of recurring ictus; and, among writers on the pulse, there are some besides Floyer * who have found nothing else to describe.

(3) *The recession, subsidence, or tailing off* of the pulse.—In reality the task of the finger is not at an end: there is more to feel, but this has to be sought at a lower level. The abruptness of the ictus tends to leave the finger expectant at the height of the wave; meanwhile, however, the pulse is running through its stages below. The finger should drop at once with the falling wave, and the artery will then be kept within touch almost without a break. Thus the third event is isolated from the ictus by its lower level rather than by any interval of time. This phase is much less momentary than the others, and does not so swiftly elude us. The feeling is one of progressive, and, as it were, silent constriction. The artery seems in the act of winding itself up, or

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* *Cf.* p. 3.

of being tightened by brief instalments, and thus, with gradually diminished size, it ultimately fades away. This process occupies nearly the whole interval up to the subsequent beat.

Among the undulations which vary this decline there is one perceptibly larger than the others. This is *the dicrotic wave*, the habitual presence of which was not suspected until shown by the sphygmograph, but which, in its exaggerated form in the so-called "dicrotic pulse," has long been familiar to physicians.

The Upstroke of the Pulse.

We can afford to postpone, as not essential to our present purpose, any further study of the events in the fall of the pulse-wave; but, since absolute precision as to the events corresponding to each of our sensations is indispensable, there is yet something to add to our description of the first period or upstroke.

Just as "the pulse"—and "the beat" of the pulse or ictus—are not synonymous terms or identical objects, two very distinct tactile events are comprised under the "upstroke" properly so called. The *onset* of the wave and *the rise* of the wave must be kept separate in the mind and, if possible—though this is difficult—in the sensations of the finger.

Here again we acknowledge our indebtedness to the sphygmograph for the lead given to our tactile method. In the pulse tracing these two events are seen in the clearest light. But under the finger the onset is so gradual and the rise is so short that great attention is required to differentiate them from the ictus. They are least difficult to perceive with three finger tips joined together; or when the thumb is laid flat along the radial artery with its tip towards the elbow. In moderately slow pulses the rise is often visible.

The *rise of the wave* can hardly be mistaken for anything else when attention is fully directed to it. But in comparative observations on the time of the pulse at different sites much care is needed to avoid a mistake.

The *onset of the wave* is more apt to escape observation than to misguide it. Nevertheless there are methods of palpation which render it apparent, and expose us to the risk of confounding it with the ictus (see p. 305).

In conclusion, a full analysis of the tactile events should enable us to distinguish five phases in the pulse:

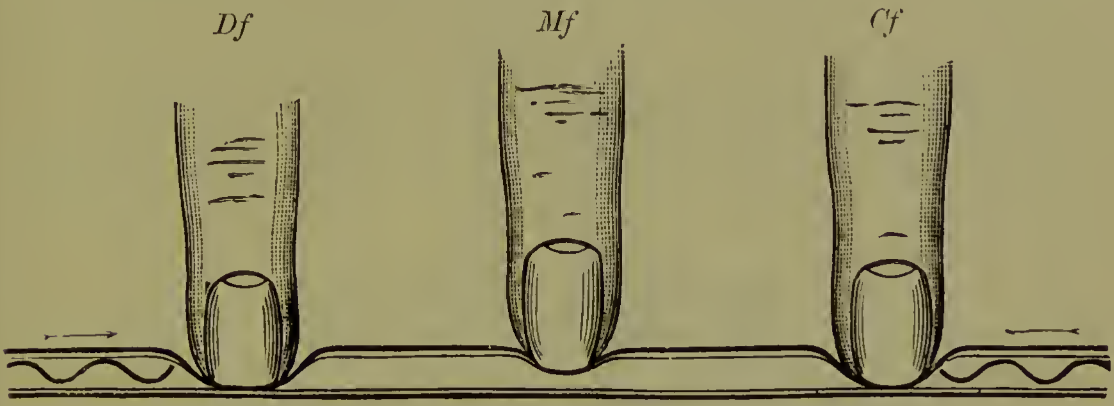
I. *The rapid upstroke, comprising the onset of the wave, and*
II. *The rise of the wave;*
III. *The ictus;*
IV. *The slow subsidence, subdivided into two portions by*
V. *The dicrotic event.*

The Anastomotic Pulse.

We may take it for granted that the strong pressure of a finger can, with rare exceptions, flatten the radial artery. Let obliterating pressure of this kind be applied by the finger *Cf* a short distance up the wrist. If another finger, *Df*, be now lightly applied to the same artery a little nearer the hand, a pulsation may still be felt at *Df* in some cases. The pulse-wave has been conveyed to the distal portion of the obliterated artery by some collateral channel. The pulse felt at *Df* is an *anastomotic pulse*, and for reasons elsewhere to be explained this term is to be preferred to that of reflux pulsation, which, however, accurately describes the direction of the wave.

The accompanying illustration, which I owe to the kindness of Dr. Douglas Powell (see *Med. Soc. Trans.*, vol. xiv.), will make it plain that the length of artery included between the two fingers will become pulseless if not only *Cf*, but *Df* also, be so firmly pressed down as to flatten the underlying vessel. Both the direct and the anastomotic pulse will then have been arrested, and a third finger, *Mf*, may be used to verify the fact.

FIG. 18.



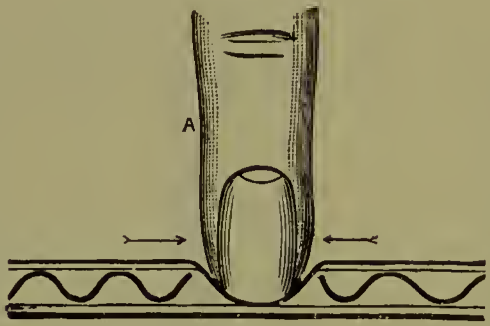
Pulseless interval between two fingers used as blocks.

In many cases, however, the pulse-wave is not transmitted by anastomosis; and the third finger will be unable to detect any pulsation, even though *Df* be but lightly applied.

A third finger is really superfluous. With a little attention the finger *Df* will, if firmly applied, be able to recognise not only the occurrence of pulsation on its distal side, but also the absence of any pulsation on its proximal side. This is a first achievement in tactile analysis: the finger is found to be capable of identifying pulsation as occurring exclusively on its distal side.

We might, however, go a step farther. *Cf* might conceivably be made to do office for all three fingers. Thus, if no anastomotic pulse should exist, being applied with full pressure, it would feel pulsation only on the side nearest the heart. If, on the contrary, a pulsation should also be experienced on its wrist side, this could only be due to the anastomotic pulse-wave. A single finger would thus be performing a threefold office: that of feeling the direct pulse-wave, that of stopping its direct progress, and that of testing for its having been transmitted or not transmitted along the palmar circuit in an ascending direction.

Fig. 19.



The direct and the anastomotic pulse, on opposite sides of the blocking finger.

The anastomotic pulse is more often present in the adult than in the young. In the latter its absence may be looked upon as the sign of a neatly balanced peripheral circulation.* We shall not be astonished, therefore, if the anastomotic pulse should disappear and reappear on successive days, or even in the course of one day, in the same individual in connection with variations in the state of the circulation.

The analytical study of the anastomotic pulse will have to be postponed until some account has been given of the ordinary pulse.

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* An habitual and strong anastomotic pulsation at the wrist is in some subjects an idiosyncrasy due to unusual size of the Superficialis Volæ artery.

CHAPTER IV.

THE ICTUS.

The Author's Early Observations on the Ictus.

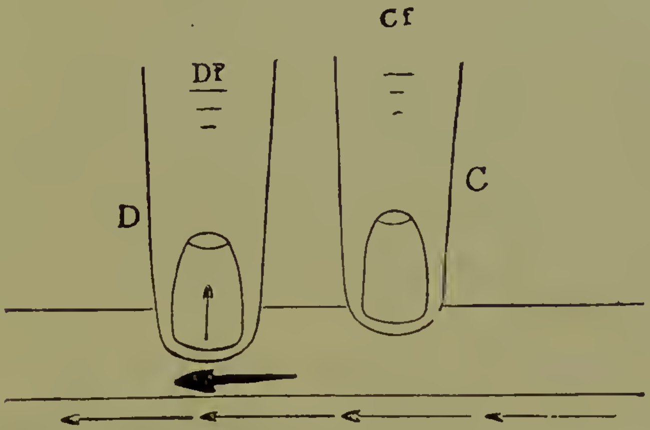
A BRIEF reference to the earlier steps in pulse analysis, and to their attendant doubts and difficulties, may be practically useful as an introduction to the present inquiry. Being the central and most sharply defined tactile event in the pulse, the ictus presented itself as the first object for study; and throughout our investigation it will retain a prominent position, not only on its own account, but as greatly assisting the study of other events.

The Localisation of the Ictus under the Finger.

When two or three fingers were applied side by side to the pulse, it was noticed that one of them appeared more specially to feel the ictus, as though the latter were a local not a general event. In harmony with this idea was the fact that, in certain positions, a distinct ictus could be seen, for instance the locomotor ictus at the wrist; at others, none. Yet it seemed impossible to conceive the normal pulse to be otherwise than homogeneous and equal to itself, at least within the space of a few inches.

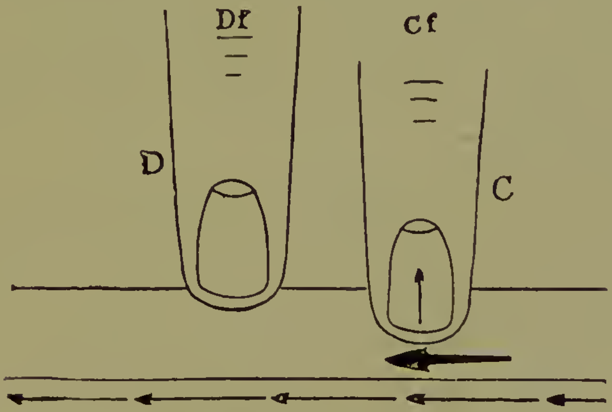
Most of the observations being made at the wrist, it was found that the ictus almost invariably seemed to strike the finger nearest the hand. This circumstance, as can now be shown, was the result of the special variety of pressure then employed (see Fig. 20); an explanation which receives collateral proof from the opposite experience (see Fig. 21) recorded by

FIG. 20.



The beat is felt under the distal finger, nearest the hand—the usual observation.

FIG. 21.



The beat is felt under the proximal finger, nearest the heart—the less usual observation.

Sir William Broadbent (*loc. cit.* p. 46): "The individual pulse-waves reach the finger nearest the heart with a definite stroke."

Was this singular localisation at the most unlikely spot related to the finger, or to the artery?

The peculiar way in which the radial artery rises from a hollow to the transverse ridge at the base of the styloid process, suggested, as a probable cause, this local prominence of the vessel; but no change was obtained on moving the fingers up to the hollow part of the wrist.

The alternative explanation, based upon an assumed difference in the sensitiveness of the fingers, was easily disposed of by applying the same fingers from the opposite side of the patient's wrist. The ictus was now felt in the same position, but by the opposite finger.

The Ubiquitous Nature of the Ictus.

Meanwhile evidence was gained that the ictus could be felt anywhere and everywhere in all accessible arteries.

Wheresoever the finger was placed on a pulsating artery, the ictus was felt, even in situations where it was not visible, as it is at the wrist. This pointed to its being not a local but a general event, not bound up with any local anatomical peculiarity of the artery. Its independence from extra-arterial influences seemed clearly established by the observation that in all arteries it could be felt on the lightest application of one finger.

On the other hand, whenever two or three fingers were applied in the usual way, the same distal perception of the ictus was noted.

A conclusion was gradually approached that the application of the fingers in some way had the effect of modifying the ictus, and that the sensation in question was in great part *manufactured.* To Dr. Tucker Wise I was indebted for a suggestion that hydraulic pressure was probably at the root of the matter; and that, beyond the part narrowed by the finger, the pressure would be multiplied by the difference between the two sectional areas. We shall perceive by-and-by that this theory does not entirely solve the question.

The variable Relation of the Ictus to the Fingers, Its Dependence on Pressure.

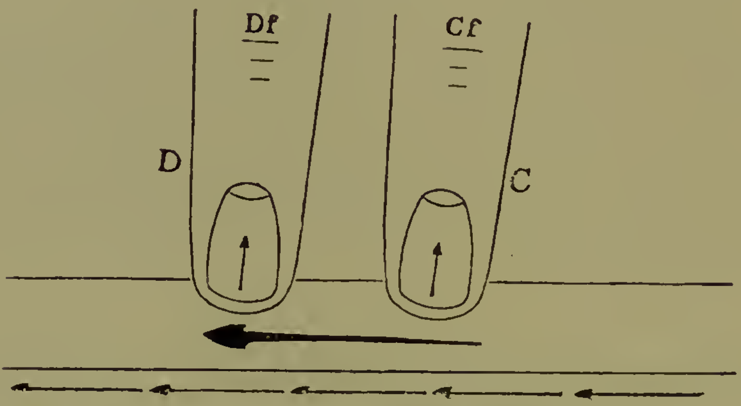
The problem assumed further complication when it was realised that, although the distally localised sensation could always be called forth, still the ictus was also felt at times, and as it were accidentally, by the proximal or by the intermediate finger, whilst the usual localisation was being felt for. In short, the localisation under the finger was a variable one, and to a certain extent could be varied at will. The following experiments gradually brought to light an intimate connection between the site of the ictus and the amount and mode of application of the pressure made by the fingers. But the full explanation of the phenomena was not obtained until the valuable work of von Kries and that of von Frey supplied the key to them.

The Localisation of the Ictus.

Experiment I.

If two fingers *Cf* and *Df* be applied to the wrist with a short interspace ($\frac{1}{2}$–$\frac{3}{4}$ inch), and with the same pressure, they will not both feel the ictus in the same degree. Indeed the ictus will seem to centre in one of them; and if *pressure ii* be employed by both fingers, the distal finger *Df* will be the one invariably impressed. (See Fig. 22.)

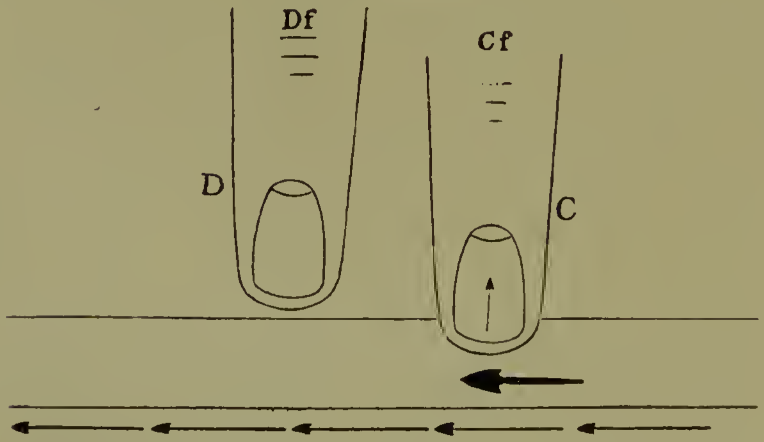
FIG. 22.



Pressure ii applied by both fingers; the ictus is felt by the distal finger.

Experiment II.

FIG. 23.



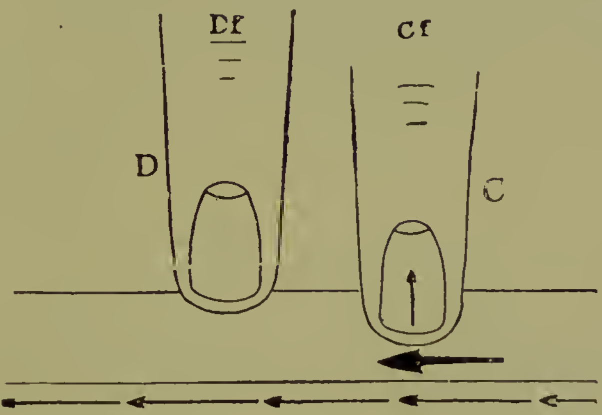
Transfer of the ictus to the proximal finger, when the distal finger is raised.

On the other hand, if *Df* be lifted, *Cf* will feel the ictus. (See Fig. 23.) But as soon as *Df* is re-applied, the ictus will again be felt by that finger.

Experiment III.

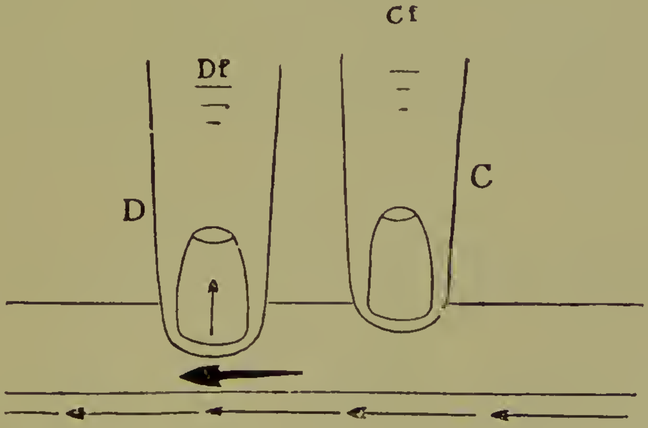
We have assumed that the pressure of the fingers was equal and moderate. Let us now vary the degree of pressure from i to iii, and alternate its application at *Df* and *Cf* respectively. Whenever the stronger pressure is made by *Cf*, the ictus will be felt by that finger. (See Fig. 24.)

FIG. 24.



Ictus felt by *Cf*, because pressure iii is applied by *Cf*.

FIG. 25.



The pressure transferred to *Df*—and, with it, the ictus.

Should *Df* once more exert the chief pressure the ictus will return to *Df*. (See Fig. 25).

We conclude from these experiments that the pressure of the finger in some way influences the localisation or the perception of the ictus. As to the mechanism of the ictus, and as to its cause, they do not afford any direct clue. The explanation is not easily given at this stage, but will evolve itself gradually from the sequel.

CHAPTER V.

THE FUNDAMENTAL PRESSURE EXPERIMENTS, CONDUCTED WITH A SINGLE FINGER.

We shall now deal with the impressions received by a *single finger*, when applied to the pulse in succession with each of the degrees of pressure which have been described (see p. 96). The examinations should be practised on a *healthy pulse*, of *good average strength*, and *free from* any anastomotic pulsation.

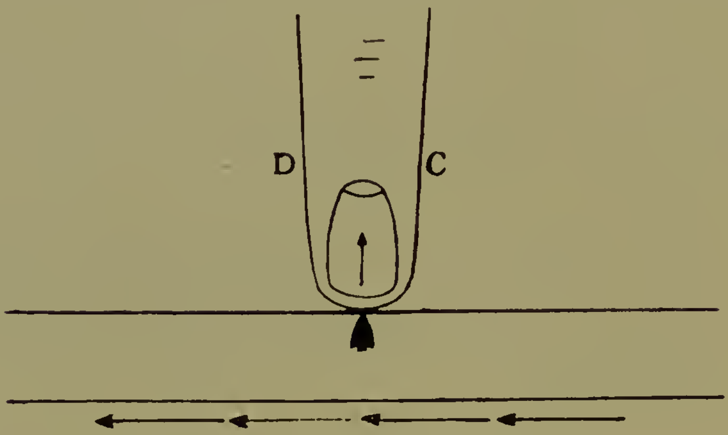
Perhaps the most convenient finger to use singly is the index. Any other finger may, however, answer as well; and it may be advisable to repeat doubtful observations with a different finger.

A. Experiment IV.

One finger applied with the lightest degree of pressure (i).

If the finger be held so lightly over the pulsating surface as to *touch without pressing*, the sensation will be delicate, and it will be perceived at the small surface of the finger then in contact—that is (supposing the finger to have been applied on end, and the hand in the usual position) *at the terminal, median, or axial point* of the convexity of the pulp.

FIG. 26.



Pressure i : The ictus is felt axially.

B. Experiment v.

One finger applied with light pressure (ii).

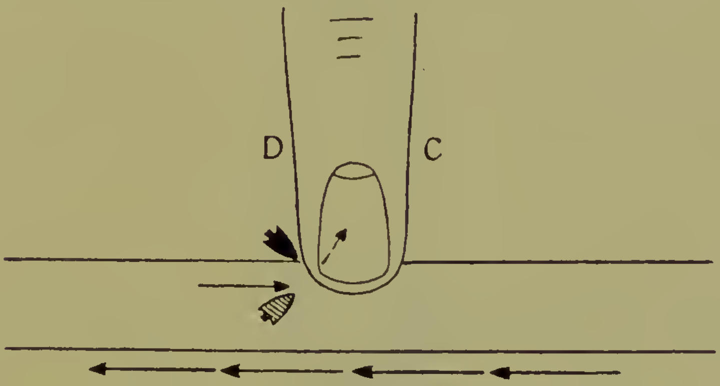
If now, from the point of mere contact, the pressure be very carefully increased, at some stage or other within the range of the light pressures, a marked change will occur in the sensations of the finger. The beat of the pulse ceases to be felt as a strictly axial event. The sensation has definitely shifted laterally; and the extent to which it may have approached the phalangeal border will depend on the extent to which the finger may have needed to be sunk into the tissues of the wrist.

This change occurs without distinction in all pulses. But here, as in the following observations also, cases will differ as to the amount of pressure required; some calling for more, others for less increase of pressure for each change.

As indicated in the figures, with each pulsation the artery will appear to rise towards the finger. This will be the only marked sensation obtained. In some cases it will be just possible to notice the receding of the artery from the finger. Sometimes it may also be realised that the beat or ictus is preceded by the swell of the wave.

The ictus itself has the suddenness of a shot arrow, but none of its sharpness. It may be slightly felt in the axis of the finger, but will be most strongly felt laterally, as shown in the diagram.

FIG. 27.



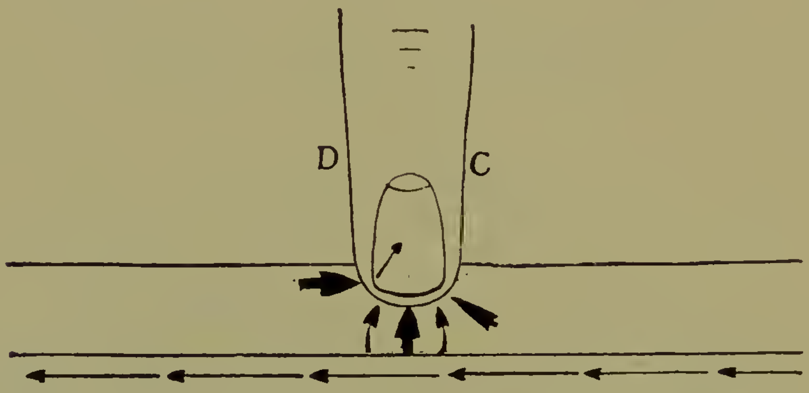
Pressure ii : The ictus moves to the distal finger border. N.B. The shaded arrow-head identifies the direction of the ictus as felt. *A duplicate* black arrow-head is placed, as in subsequent diagrams, above the artery, for convenience.

The diagram purposely indicates a pressure sufficient to bring the end of the *phalangeal border* into contact with the artery.

The side to which the sensation invariably shifts is not, as might have been expected, the proximal, C (or central), but the *distal side*, D. This circumstance, which greatly exercised the writer for some time after his first noticing it, is capable of explanation, and this will be given at another place (see part V. p. 298).

A first attempt may not always succeed; and in case of failure, the observer would do well to try again with a larger pulse. It might, however, suffice to use the middle finger if the index should fail; or whilst continuing the attempt with the index, to approach the pulse from the ulnar instead of the radial side. We should not forget, however, that the prehensile function of the radial border of the index noticeably detracts from its tactile sensitiveness.

FIG. 28.



The sensation of ictus (under D) preceded by that of the onset of the wave (under C).

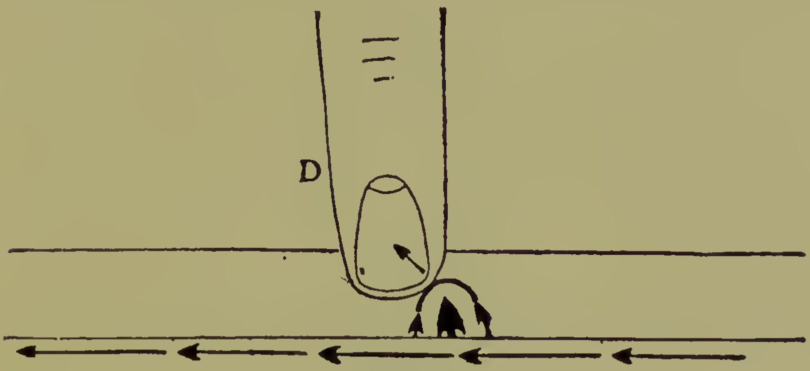
In addition to the ictus which is felt on the distal side, as stated above, it is easy to feel, preceding the ictus, the advent of the wave and its rise. The fact that they are perceived keenly by the axial portion of the finger pulp, and indeed by the whole pulp surface applied to the artery, although less distinctly at the proximal border, renders it the more striking that the ictus should be felt at the distal border only of the phalanx.

The sensations due to the wave explain the difficulty experienced by some observers at their first trial: the onset of the wave possessing some abruptness may simulate the ictus and rather impede the separate appreciation of the latter.

Any suspicion that the sensations described in connection with this experiment are merely subjective is readily set aside. Check experiments will be described on page 125, which confirm the observations detailed above.

Again, when the pulse under observation is a strong one, the finger may be seen to be lifted at each beat, not vertically, but somewhat obliquely—in this case in a centripetal direction, though the diagram shows the opposite.

FIG. 29.



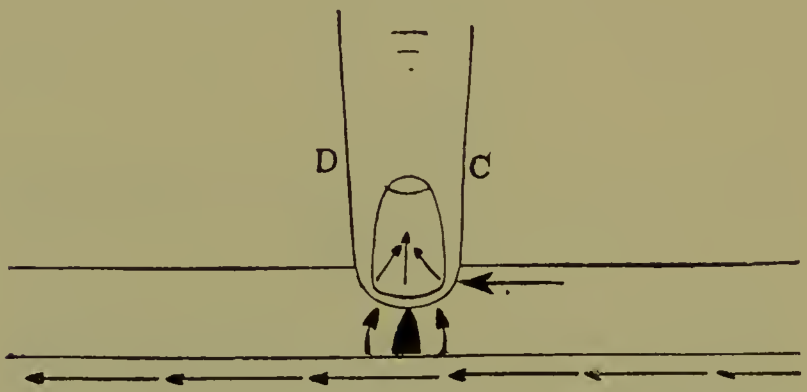
Illustrating the oblique movement imparted to the finger by a strong lateral ictus. The diagram represents the finger pushed in the opposite direction (centrifugal) to that described in the text.

C. Experiment VI.

One finger applied with moderate pressure (*iii*).

Here again the requisite amount of pressure cannot be predicted, but we have to be guided entirely by the result. This stage of the analysis, corresponding to a very short range in the scale of pressures, is rather apt to be overlooked. On increasing very slightly the previous pressure, the sensation of pulse again shifts its locality. It leaves the side of the phalanx and returns to the central part of the pulse. The finger end now presents a wider surface of arterial contact than heretofore, owing to its deeper descent into the tissues. Along the whole of this surface the ictus is felt, instead of in the axial portion alone (as in Experiment *A*). For the reason just stated, the feeling spreads to a small part of the phalangeal borders. At a given proportion of pressure, and only then, this form of reaction will be at its acme (Fig. 31), and the sensation of ictus will extend evenly under the finger-tip and to both its sides, without, however, rising so high up the finger border, as the ictus in the previous experiment.

FIG. 30.



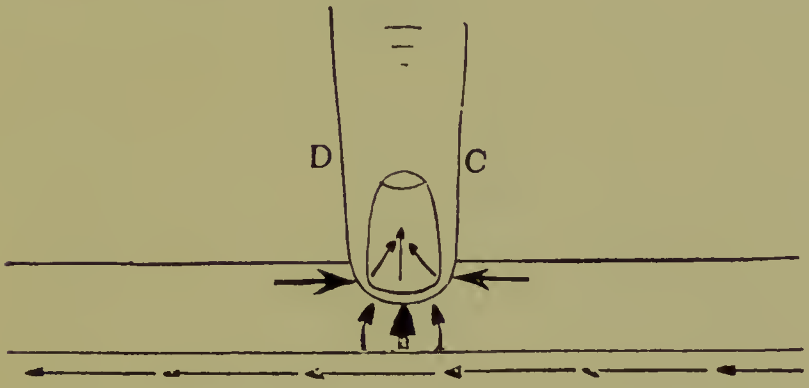
Pressure iii: The ictus is felt axially, as in Experiment A; but over a wider surface. The onset of the wave is figured by the arrow (under C).

In addition to the ictus, the finger at this stage obtains a very good palpation of the pulse-wave, not only during its rise, but to some extent also during its fall.

In connection with the feeling of wave, it is to be noted that at the acme of this reaction the direction of the wave cannot be clearly determined by the finger. With more or with less pressure a direction will be recognised; the sensation being, in the one case, centripetal—in the other centrifugal.

This pressure might be deemed, at first thought, that of election for feeling the pulse, and, of all others, the clinically useful one. Owing, however, to the difficulty of finding the exact degree of pressure corresponding to the perfect equilibrium of sensation, which has been described, this is not the case. Moreover, the amount of information to be gained is not to be measured by mere symmetry of the sensations.

FIG. 31.



Showing extensive range of sensation of ictus, under the same pressure. (The later wave-sensations are not readily depicted.)

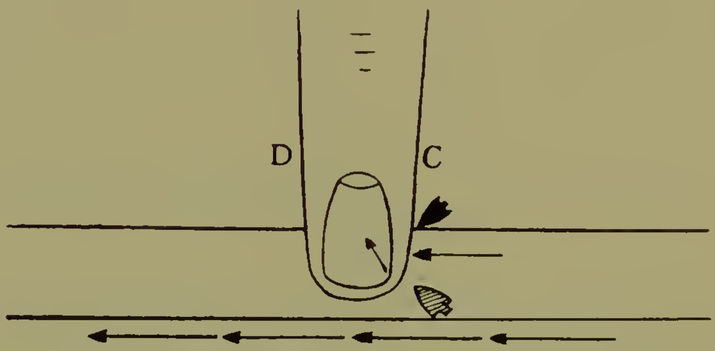
Enough has been said of the fugitive nature of this reaction to explain how it may chance to be missed altogether, where the pressure is increased without sufficient care, or where other circumstances are unfavourable. Then the sensation of ictus would appear to undergo sudden transference from the distal to the proximal side of the finger.

D. Experiment VII.

One finger applied with stronger pressure (iv).

With slowly increasing pressure the sensations lose more and more their previously symmetrical character, and tend to become limited to the proximal half of the under surface of the pulp. This exact distribution is, however, very difficult to bring about, owing to its very short range. Usually, with some suddenness, the ictus ceases to be prominently felt by the flat of the finger-pulp, and it makes its appearance at the *proximal phalangeal border*, in a situation exactly symmetrical with that it previously occupied (in Experiment *B*) at the distal border.

FIG. 32.

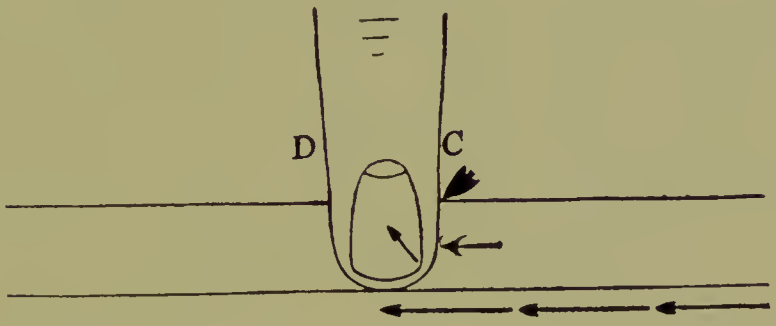


Pressure iv: The ictus migrates to the proximal finger border, striking in the direction shown by the shaded arrow-head. N.B. The black arrow-head is a duplicate of the latter. The thin arrow indicates the onset of the wave.

This is the final position attained by the ictus. The pressure may be increased gradually without displacing the latter from the proximal border. But as the finger sinks more deeply into the soft parts, the ictus will ascend to a higher level along its side, whilst sensation may be blunted or lost over corresponding portions of the extremity of the phalangeal border.

It is a peculiarity of this reaction that the *wave is not felt* by the finger. At most the sharp onset of the wave may be distinguished as a beat immediately preceding that of the ictus. The significance of this double beat will be discussed in due place (see Part V. p. 305). The wave in its continuity ceases to be perceived.

FIG. 33.

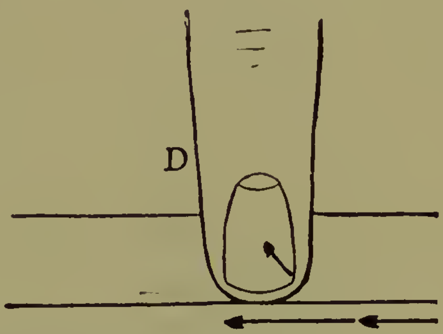


The head of the pulse-wave may be felt (thin arrow) striking the finger; but the body of the wave is not perceived with this degree of pressure.

It is also distinctive of this reaction that any degree of pressure may be added in excess of that requisite for its production, without inducing any further change in the localisation, though the strength of the impression will be modified. The force of impact will vary according to the strength of the pulse, but it will remain, comparatively speaking, considerable, so long as the pressure of the finger is not excessive. With very great pressures less and less of the ictus will be perceived, until the sensation in some cases almost vanishes, or is reduced to diminutive proportions.

Practically speaking, the setting-in of the ictus at the proximal side of the finger marks the moment when the wave ceases to be transmitted beyond the latter. The artery may not be absolutely flattened yet; for this a very slight additional pressure will suffice. This experiment may therefore be said to include the obliteration of the artery (fifth degree of pressure).

FIG. 34.



Pressure v (forcible): Partial or complete loss of the perception of ictus.

The vanishing, under forcible pressures, of the ictus (in some instances) will be explained later on.

Tactile Analysis best begun with Experiment D.

In the long continuance of this final reaction through an extensive range of pressures, we possess a ready means of making sure of obtaining the results described. For this reason it is advisable, at least for the untrained, to begin with this experiment *(pressure iv)*. The existence of the proximal ictus being once recognised, the other stages of the analysis will be more readily mastered.

If during the performance of this experiment the beat of the Radialis Indicis be kept under ocular observation, its pulsation will be noticed to become fainter, whilst increasing pressure is made on the radial artery. At the exact moment when the ictus is felt at the proximal side of the finger, the pulsation will cease to be visible.

N.B.—Should an anastomotic pulse exist, this will very soon restore some pulsation in the Radialis Indicis, but of a different type from that which obtained up to that time. The peculiarities of the fresh pulsation will be further described in connection with the anastomotic pulse (see p. 169).

Brief Review of the Results hitherto Obtained.

Experiment A: Very light pressure *(i)*, hardly exceeding that of simple contact, is made on the artery. The sensation of ictus is limited to the extremity of the pulp applied to the vessel. Something of the pulse wave may also be felt.

Experiment B: Slightly increased pressure *(ii)* will cause the ictus to be felt at the distal phalangeal border. The progress of the wave will now be more plainly felt under the pulp of the finger.

Experiment C: With care, further pressure *(iii)* will cause the ictus to be felt under the centre of the pulp, and less plainly at the extreme phalangeal borders. Whilst the wave is felt over the whole surface of contact, its direction is not clearly perceived.

The third degree of pressure thus restores the ictus to the median situation. We shall see by-and-by that this intermediate pressure is often accompanied with *thrill.*

Experiment D: Stronger pressure *(iv)* entirely deprives the flat of the pulp of the feeling of pulse-wave and of the sensation of ictus, which is now exclusively perceived at the proximal phalangeal border—preceded only by an exceedingly brief impact of the pulse-wave.

These four fundamental observations are the basis of all further pulse analysis, and in that connection they need to be thoroughly understood and verified by the reader.

All the sensations which have been described are more or less plainly called forth in any ordinary palpation of the pulse, but the proportion in which they are blended is inconstant, and the resulting composite sensation must vary with each observer. So long as they fail to be isolated, clear deductions must fail to be drawn from each of them ; it is most unlikely that a distinction will be made between the wave and the ictus ; and the localisation of the ictus will, of course, escape recognition. Any definite conclusion that might be framed would remain of an elementary order, and would chiefly relate to the general characters of suddenness, short duration, and predominant upheaving action peculiar to the pulse beat. This is precisely the kind of description given by the earliest authors under the name "micatio," and still current among us.

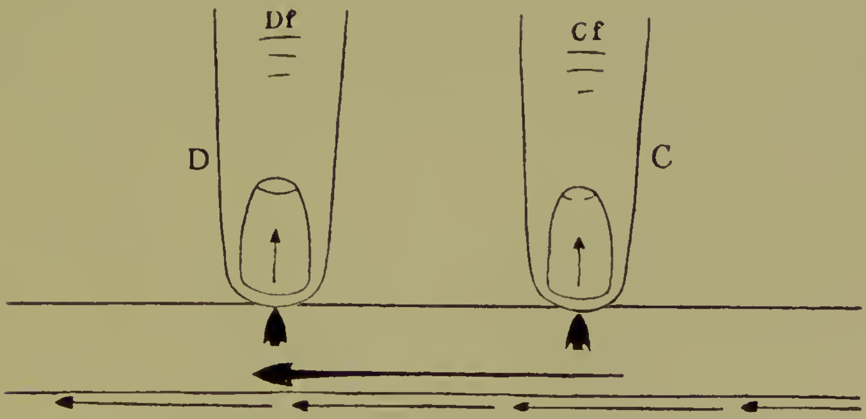
Check Experiments with the Help of a Test-Finger applied below the Pressure-Finger.

The same series of observations should be repeated with the additional help of *Df*, a finger from the other hand, very lightly applied to the wrist nearer the hand. This arrangement has the advantage of supplying information as to the existence or absence in the subject of any anastomotic pulse. We will suppose for the present that there existed none. It should be stated that the finger *Df*, applied lightly as a testing finger, will not in any way modify the results, which *Cf* will continue to feel.

Experiment VIII.

So long as *Cf* exerts light pressure only, the pulse is perceived at *Df* as before.

FIG. 35.

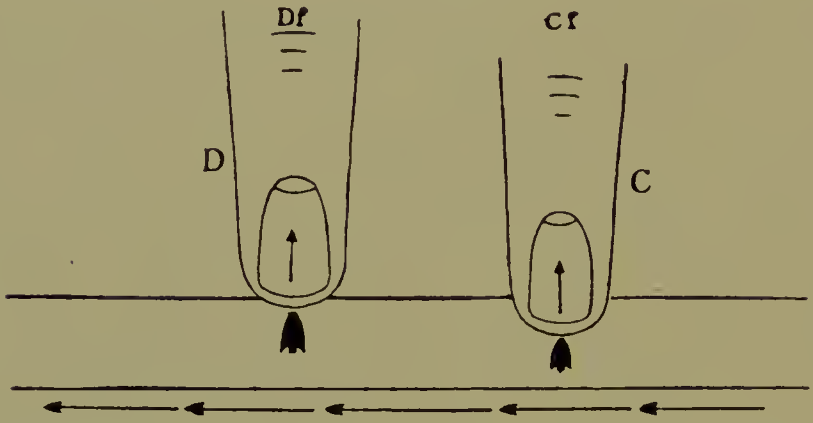


Pressure i : *Df* as test-finger feels the ictus, as does *Cf*.

Experiment IX.

Moderate pressures at *Cf* will not materially alter the conditions in respect of *Df*. With pressure ii, and even throughout the range of pressure iii, pulsation will still be felt at *Df.*

FIG. 36.

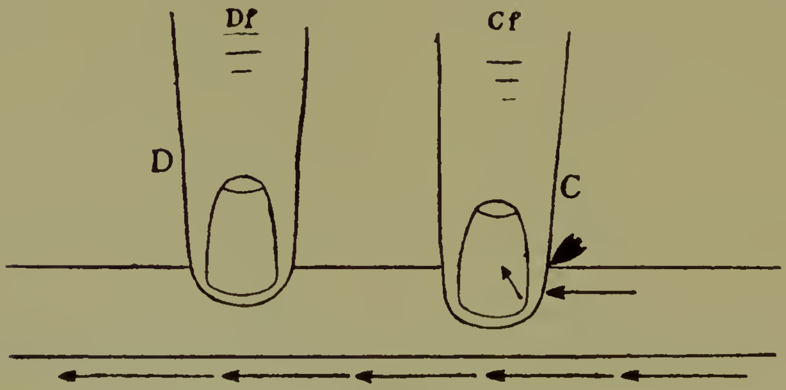


Pressure iii: *Df* still feels the ictus; though more and more faintly with growing pressure.

Experiment x.

Deeper pressure will (the anastomotic pulse being absent) put an end to all pulse sensation at *Df.* Nothing will be felt beyond *Cf.*

FIG. 37.



Pressure iv: *Df* loses all sensation of ictus and of pulse-wave.

It is well to entrust to the finger of another observer the testing for the absence of pulsation. This is a safer means of confirming the often-repeated observation that *the moment of the appearance of an ictus at the proximal phalangeal border is also the moment of stoppage of any palpable pulsation beyond.*

[N.B.—In these experiments the test-finger is supposed to be farther removed from *Cf* than in the entirely distinct experiments with paired fingers (see p. 130).]

Thus it is clear that, if the pressure of the proximal finger be sufficiently light, the wave will travel on. If now the distal finger be applied with varying pressures, it will perceive the same graduated sensations which we have previously described in connection with the proximal finger.

With growing pressures at *Cf*, less and less of the pulse-wave will be transmitted, until it altogether ceases to be felt at *Df*.

The influence of the application of pressure on the artery higher up is a separate matter for investigation; and with this view the testing-finger should be applied above the pressure-finger. This subject being one of some importance, will be separately considered on p. 158.

CHAPTER VI.

THE PULSE-SENSATIONS WHEN TWO OR MORE FINGERS ARE USED.

I. THE IMPRESSIONS CONVEYED TO TWO FINGERS SIMULTANEOUSLY APPLIED TO THE PULSE.

THE multiplicity of sensations, being so great with one finger, cannot fail to be greater with two. We must be prepared for a reduplication of the sensations of the single finger or, the passage of the wave being so rapid, at least for an overlapping of the sensations. In either case the impressions would become less distinct and at the same time more prolonged.

But there are worse sources of complication than the mere increase in number. Lack of uniformity in the acuteness of feeling of the two fingers, and the unevenness, or imperfectly sustained equality, of their pressures are possibilities of confusion which did not exist in connection with the single finger.

There are also in the combined use of two fingers inherent or physiological peculiarities by which sensations are apt to be modified. When two fingers are paired in work, each of them loses a portion of its individuality, so that the diversity of their sensations is thereby reduced. A second result, well known to physiologists, is the transfer and reinforcement of the sensations of the side of one finger by those of the contiguous side of the next finger. Thus the individual sensations of each would become less complete, and their joint sensations would acquire greater force. The tendency will be for the two fingers to combine their impressions, and to a certain extent to palpate as one finger might palpate; with this difference, however, that the non-contiguous phalangeal borders are farther apart, and that the surface of the pulp used is doubled, and possesses a central area of reinforced capacity for feeling. At best, therefore, this combination is but a distant imitation of the single finger.

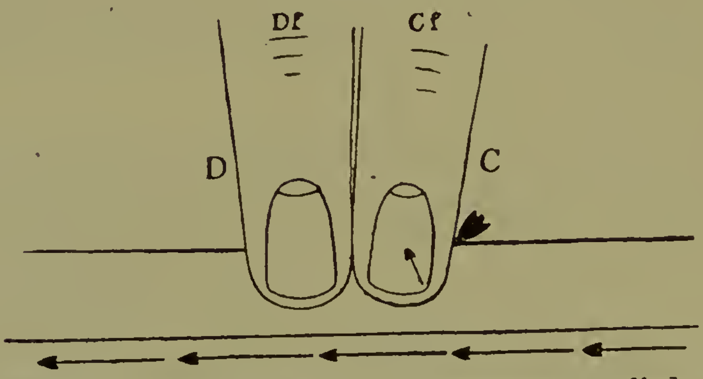
When, however, the two fingers are not in mutual contact, the resemblance is at an end, and the conditions are entirely novel. We may therefore assume, and presently we shall be able to explain, that palpation must have different results according as the fingers are held apart or in firm mutual contact. The latter is the usual plan; and it was in this way that the author's first observations of the ictus were made (see p. 92), three fingers being then used. A separate consideration of these two combinations is necessary.

A.

Analysis of the Pulse Sensations of Two Fingers applied to the Pulse, the Fingers being in Firm Mutual Contact.

In repeating the original series of "fundamental" experiments, with paired fingers, it is best to begin with *Experiment D*, the simplest to apply and the easiest to interpret. The application of obliterating pressure, either by means of both fingers or even of the proximal finger alone, will give precisely the same sensations as previously recorded with one finger. A solitary ictus, limited to the proximal side of the central finger, will be the result.

FIG. 38.

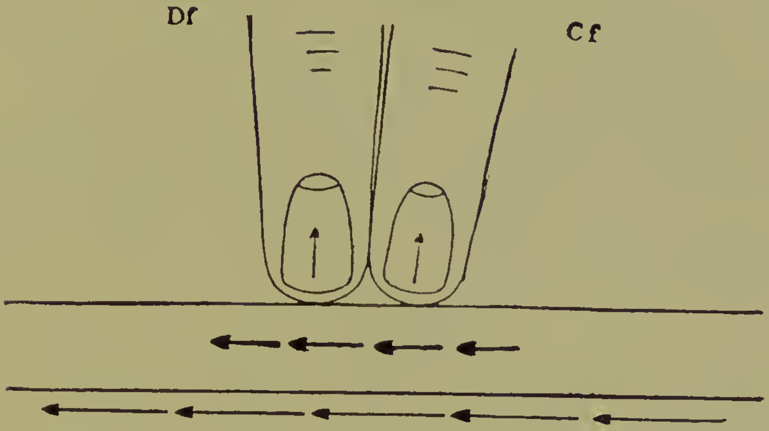


Pressure iv (or pressure v—obliterative) applied with paired fingers : Ictus felt by *Cf* only, on its proximal side.

In further experimentation with the other degrees of pressure, it is extremely difficult to be sure that the weight applied by the two fingers is exactly identical. We shall proceed on the assumption that it is.

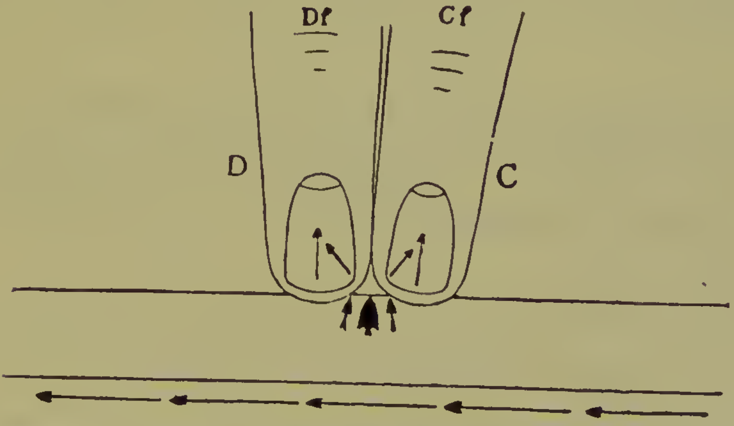
Experiment A.—With very light pressure two sensations may be evenly distinguished by the flat of each of the two pulps (very little being felt by their extreme sides). One is the sensation of a centrifugal wave moving under the finger. This was only feebly obtained with the single finger.

FIG. 39.



Pressure i: The progress, or undulation, of the wave is perceived by the paired fingers.

FIG. 40.

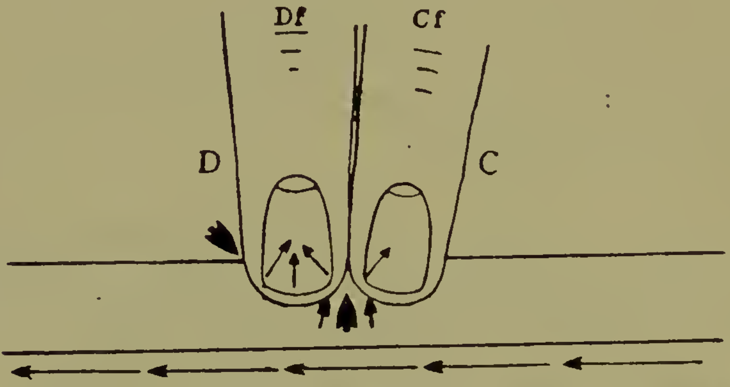


Pressure i: The ictus striking upwards against the fingers.

The second is a feeling of upheaval, analogous to that previously described, but giving the impression of a more ample curve. This is the ictus, felt by the two digital extremities. But for its flash-like rapidity, it would probably have been realised as a double, instead of a single impression.

Experiment B.—At this stage more than at any other, viz., when the pressure is increased from i to ii, the sensation will depend on the proportion of pressure exercised by each of the two fingers. The occurrence of an ictus on the distal side of the distal finger *Df* will be the first thing to attract notice. In this respect no difference occurs.

FIG. 41.



Pressure ii: The ictus is felt distally (below *D*). It is also perceived between the paired fingers; thus striking *Df* on both sides.

If the pressure of the proximal finger be less than that of *Df*, nothing further will be experienced by *Cf*, beyond the moving wave, as described on page 131.

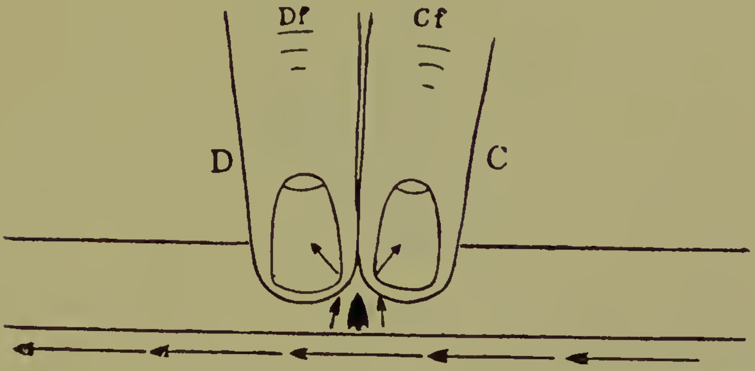
Should, however, *Cf*, as intended, be bearing with an equal amount of pressure on the artery, the sensation of ictus will not be limited to the distal border of *Df*, but the ictus will continue very perceptible under both pulps; and together with it the undulation previously mentioned. The ictus, however, is not felt evenly under the whole surface of contact, but tends to be localised at the junction between the two. This will be more fully explained under the following heading.

Much less is the ictus evenly felt by the pulp and by the distal border. There is a great preponderance of sensation at the latter.

It should be pointed out that, whenever two fingers are used, that nearest the wrist has a position of advantage, owing to the lessening bulk of the muscles and to the larger surface of bone. The relative strength of the distal ictus, to which reference has been made (see p. 107), also tells in its favour. The distal finger and its distal side thus become, or tend to be, as it were, the centre of sensation.

Experiment C.—When one finger was used the effects of this degree of pressure were not strongly marked. With two fingers they are most definite. The feeling of wave is still there, but it is blended with and, as it were, subordinate to the feeling of ictus. The ictus is bulky and strong, with a big heave *striking between the two fingers.*

FIG. 42.



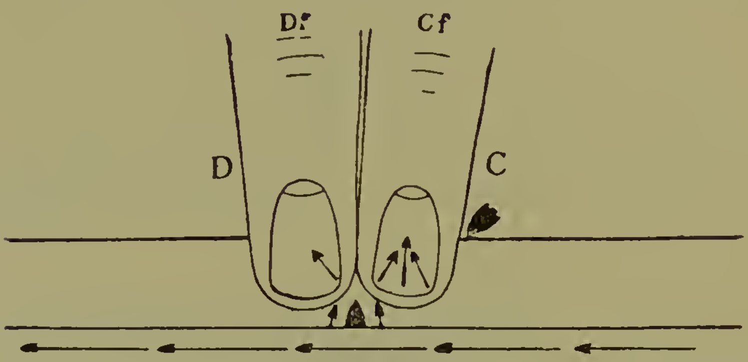
Pressure iii : Strong ictus felt between the paired fingers.

This localisation in an intermediate position, and this lumpy character of the ictus, were already foreshadowed in the sensations described in *Experiment B.* The beat almost seems to possess solidity and to wedge itself between the fingers, and its surface to be smooth and round.

Some explanation for these features has already been hinted at. The ictus, which in the case of a single finger has its seat immediately beneath the pulp, becomes in this case centred where the sensitiveness is greatest, viz., at the contiguous phalangeal borders, the tactile surfaces reinforcing each other's impressions.

Experiment D.—We now revert to our earlier experiment, to explain that the occurrence of any ictus at the junction of the paired fingers, in addition to the ictus at *C*, should be regarded as an exception to the rule, and as accidental. It would indicate that greater pressure had, unconsciously, been exerted by *Df* than by *Cf.*

FIG. 43.



Pressure iv: Any ictus between *Cf* and *Df* indicates that their pressures are not even; and that greater pressure is being made by *Df.*

B.

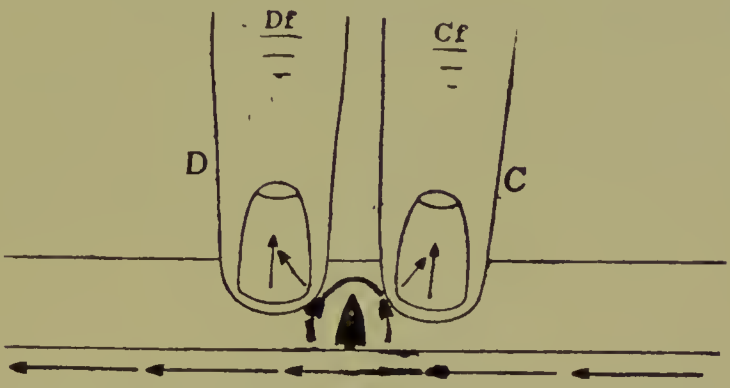
Analysis of the Pulse Sensations of Two Fingers applied to the Pulse, the Fingers not being in Mutual Contact.

Whenever the fingers are not in firm mutual contact, the result will altogether depend upon their interval.

(a) The Interval between the Fingers is trifling.

The events in this case will closely resemble those previously described.

FIG. 44.



Pressure iii: The enlarged sensation of ictus; and its projection at the interspace between the fingers.

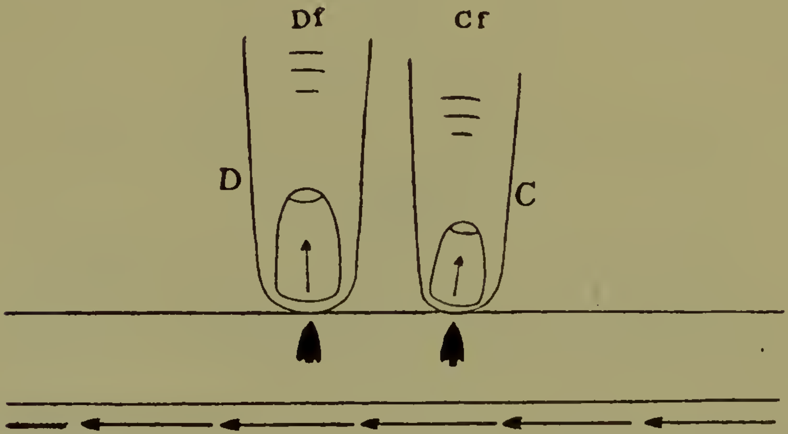
In *Experiment C* the seat of strongest pulsation will be the interspace between the fingers; and the relative strength of the pulsation, there felt, will be even in excess of the actual strength belonging to the pulse. This exaggerated sensation is due to the fact that, unless the two fingers be crossed, as in a familiar physiological experiment, the double ictus will be felt as a single one by the two surfaces accustomed to feel mutual contact; and this will be experienced even by observers conversant with the analysis of the pulse. The two sensations will be summed, as well as fused together. To Fouquet belongs the credit of having first described this peculiarity, though he does not seem to have suspected its cause.

(b) The Interval between the Fingers is marked.

If the interval be not less than one-third to one-half of a finger's breadth, the conditions will be perceptibly modified. We shall practically be feeling with two single fingers, each capable of the sensations of distal and of proximal ictus.

In *Experiment A* the perception will no longer be of one, but of two points of contact.

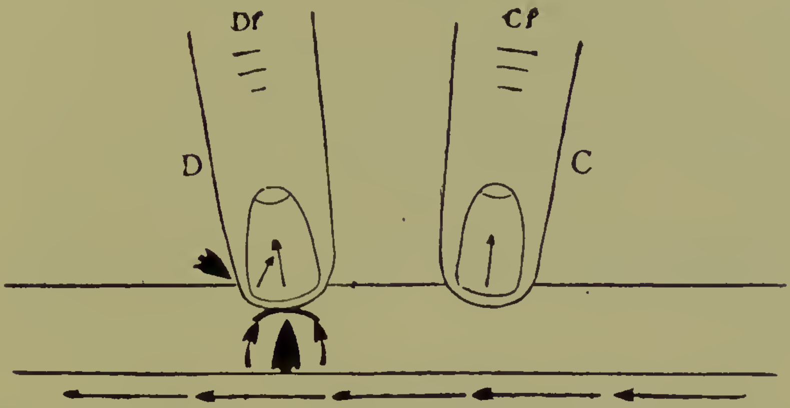
FIG. 45.



Pressure i: The fingers too far apart to feel the ictus as a single event.

On applying pressure ii (*Experiment B*), the rise of the wave will be felt distinctly by the two fingers, but the same cannot be said of the ictus, at least in the majority of instances. Although an ictus may be felt, with the help of special manipulation, at the distal border of the proximal finger, as a rule it is not noticeable, probably owing to the marked predominance of the feeling of ictus at the distal finger.

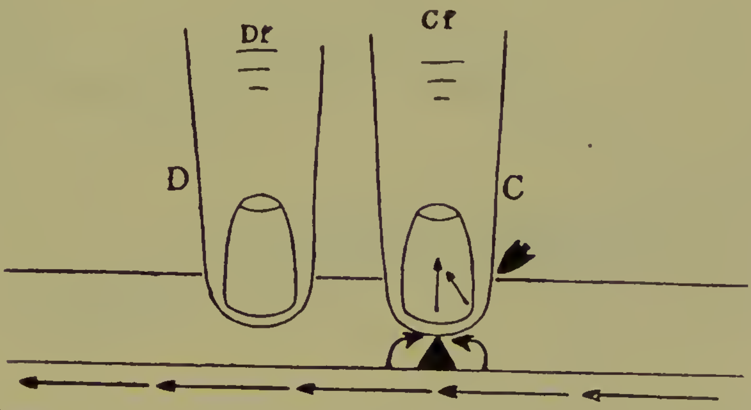
FIG. 46.



Pressure ii: The ictus felt mainly, or alone, by the distal finger, which seems to be lifted at each beat.

The peculiarity of the ictus in this case is that it appears to *lift the distal finger tip.* The mind is less impressed, than when one finger only is on the pulse, with the distinction between the proximal and the distal borders; although with further attention they will readily be distinguished.

FIG. 47.

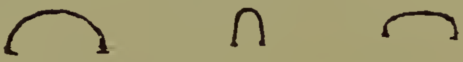


Pressure iv: The sensation of ictus is limited to the proximal side of *Cf;* except during the lighter degrees of pressure iv, when the finger may feel as though lifted bodily by the beat.

Experiment D is also apt to give rise to a sense of lifting of the proximal finger, when the pressure is not such as to produce obliteration of the arterial channel. As soon as this has occurred, the ictus is felt exclusively at the proximal finger border.

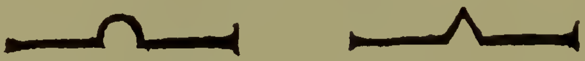
The results of *Experiment C* performed with an interval of half a finger's breadth are remarkable, and possess historical interest, having been accurately described and depicted by Fouquet, and apparently obtained, at a much earlier date, by Struthius.* The following diagrams, reproduced from the interesting work of Struthius, are conclusive evidence that he was familiar with the sensation of *prominent ictus;* but he does not, unfortunately, specify the mode of palpation which enabled him to perceive it.

FIG. 48.



Struthius (*loc cit.*), p. 94 : "Quod si has tres arteriæ figuras characteribus exprimere velis, isti erunt. Circularis, angularis, depressa." . . . . p. 95 : "Angularis figura arteriæ, si multum se extulerit ad tactum, altum et angustum indicat pulsum : si vero emineat parum, humilem et angustum. Depressa arteriæ figura, latum et humilem indicat pulsum."

FIG. 49.



Struthius (*loc. cit.*), p. 58 : "Quod si quoquo modo depingi hæc possint, pulsus convulsivus similis est dum distenditur, lineis incurvatis modicè, utrinq ; tensis, vibratus vero lineis multum inflexis in altum, et acuminatis cujusmodi etiam figura est chordæ in arcu fortiter tenso, seu vibrato, qua parte ei sagitta opponitur acuminatæ."

With this degree of pressure the sensation of ictus or of pulsation is not, as in the other cases, limited

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* Doubtless this peculiarity is more distinctly perceptible in certain pathological states, but it is essentially physiological.

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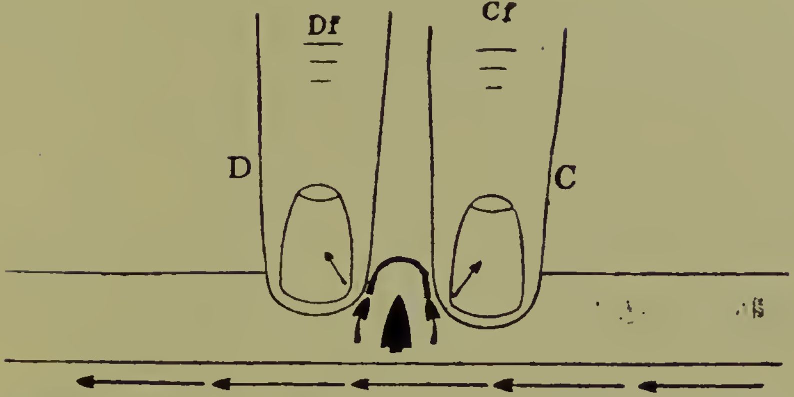
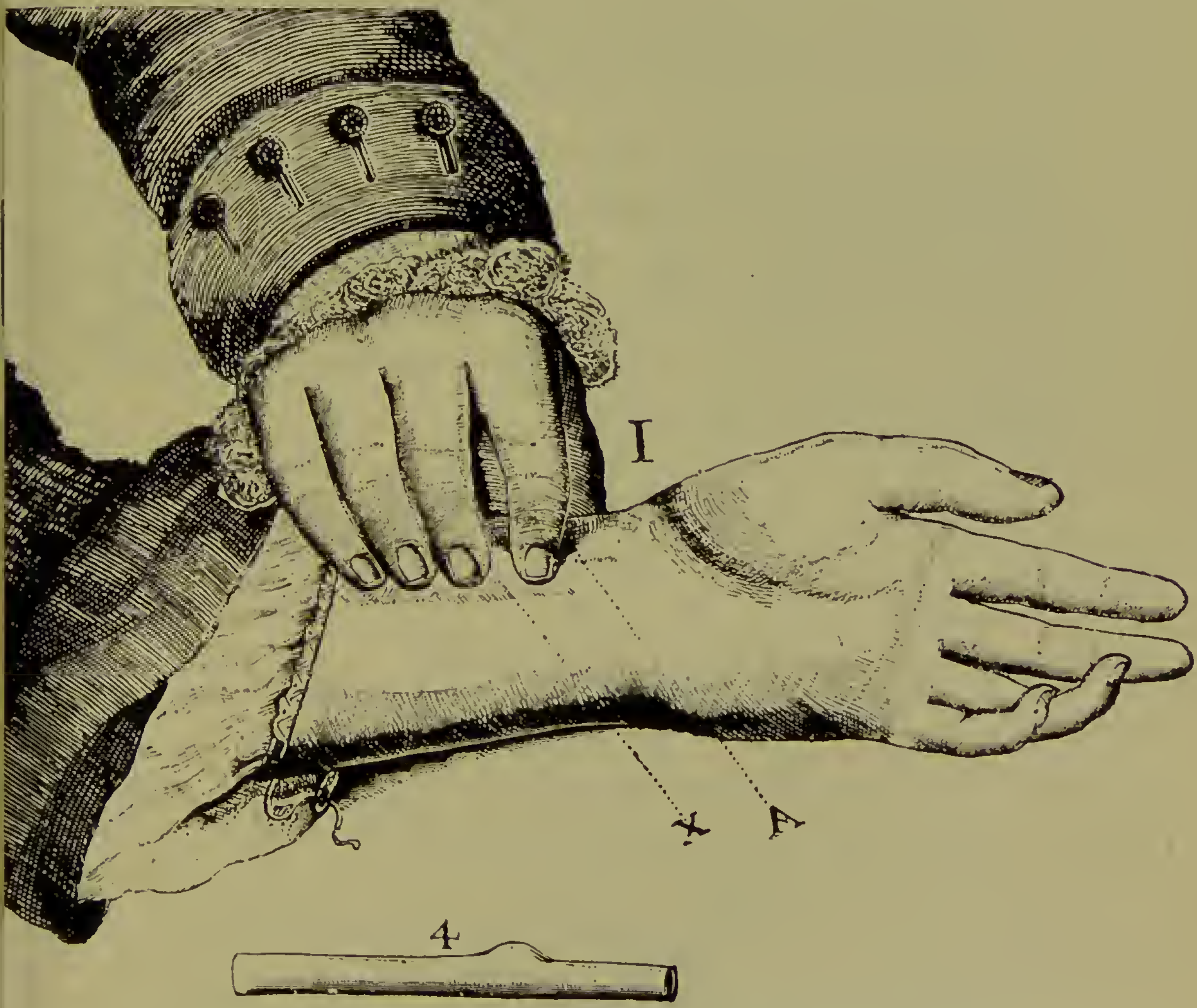
FIG. 50.



Pressure iii: The ictus is felt jointly by the two fingers, as a prominent swelling, rising between them above the arterial level.

FIG. 51.



Facsimile of Fouquet's original illustration of the pulsatile knob felt and seen between the fingers, in the "stomachal" variety of pulse.

to one of the two fingers, but is shared by both, and yet it remains a single sensation. It resembles a rounded body rising between the fingers. As stated by Fouquet, this prominence can also be seen between the two fingers, in the lean subject. This circumstance gives further interest to the observation, and in connection with it additional remarks will follow (see p. 158, Oliver's " Expansile Reaction.")

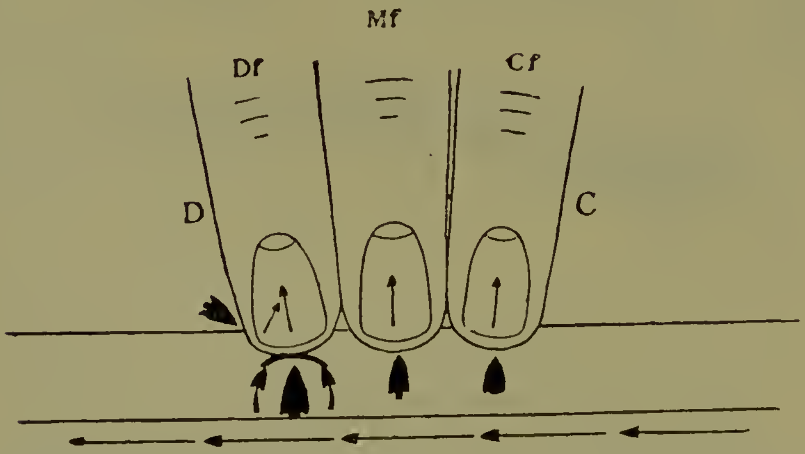
It should be added that in the performance of this experiment a thrill is often noticed.

II. THE SENSATIONS PERCEIVED BY THREE FINGERS CONJOINED.

It is unnecessary to follow out in full detail the complications which arise when three or four fingers are used jointly. The same principles will apply, and with the help of the explanations already given, any one can work out for himself the peculiarities special to each combination.

Experiment XI.

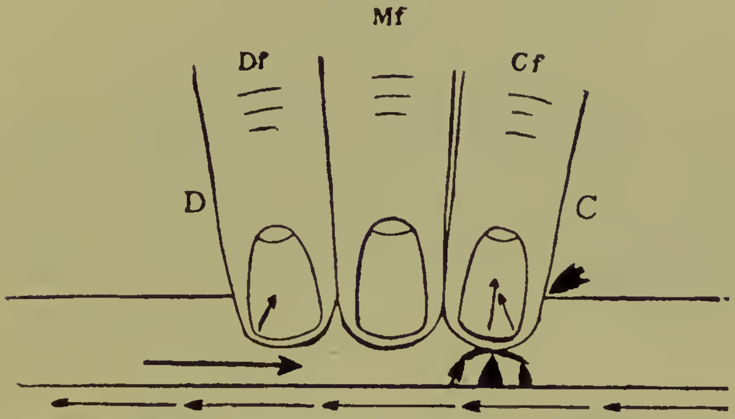
FIG. 52.



Pressure ii : The ictus and lift occur at *Df;* a slight ictus also felt by *Mf* and *Cf.*

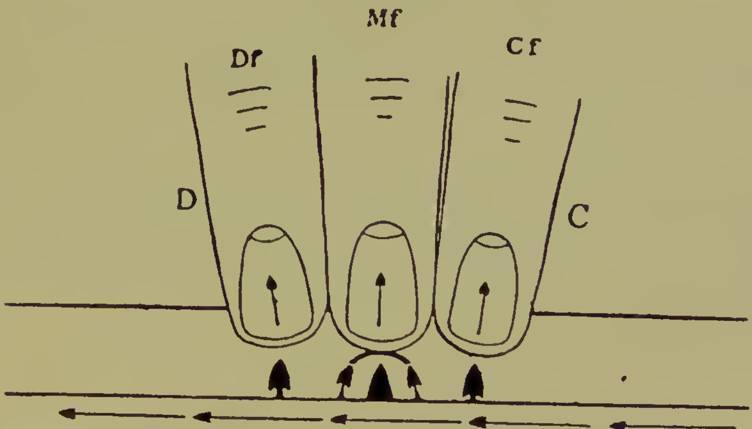
With three fingers kept in firm mutual contact the feeling of wave-progression will be very distinct under light pressure. Here again the distal ictus (pressure ii) will be perceived under the pulp of the distal finger; and the proximal ictus (pressure iv), under that of the proximal finger, both fingers experiencing in turn the sensation of lift.

FIG. 53.



Pressure iv: The ictus and lift restricted to *Cf;* any sensation experienced by *Df* is of a different order (anastomotic).

FIG. 54.



Pressure iii: The ictus and lift centre in *Mf;* slighter ictus at *Cf* and at *Df.*

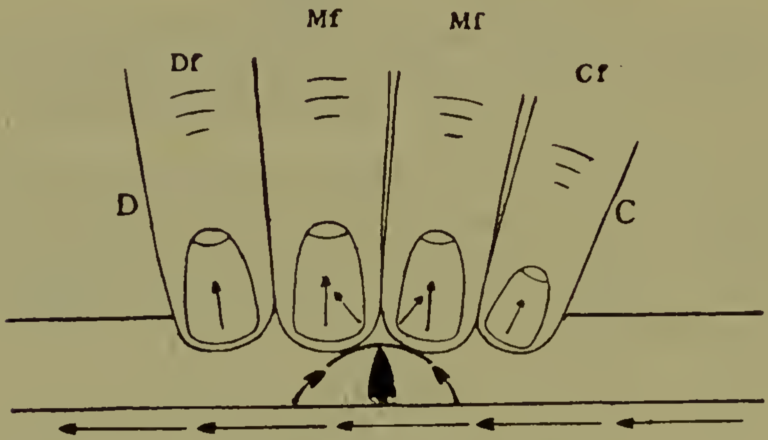
The intermediate ictus (pressure iii) will be localised under the pulp of the intervening finger, *Mf,* which perceives it strongly, the adjoining fingers sharing to a slight extent in the sensation.

III. The Sensations perceived by Four Fingers Conjoined.

Experiment XII.

With four fingers applied with pressure iii, in the same way as in the preceding experiment, the intermediate ictus will be perceived by the two intermediate fingers. Owing to increased sensitiveness at their conjoined borders, there will be inequality in the perception of the progress of the wave, which will thus give rise to a worm-like feel, and in some cases to a thrill.

Fig. 55.

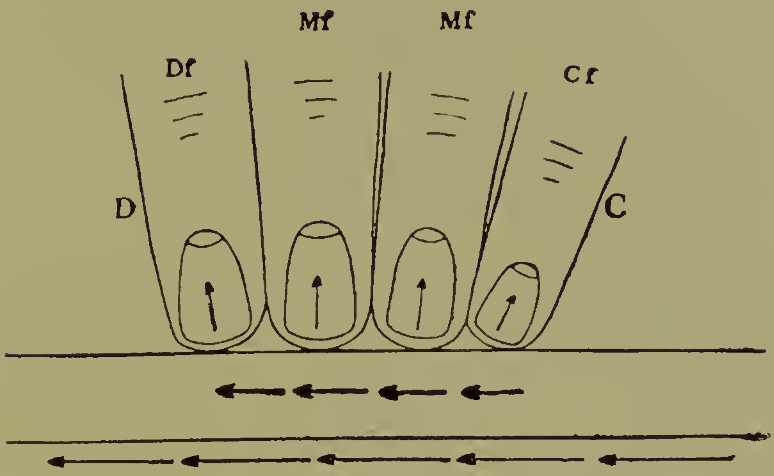


Pressure iii: The ictus and lift felt, mainly by the two fingers *Mf;* slight ictus also felt by *Cf* and *Df.*

Experiment XIII.

The progression of the wave is also prominently felt with pressure i; in this case because there is equality and separate perception of the ictus which strikes each finger in succession, in an axial direction.

FIG. 56.

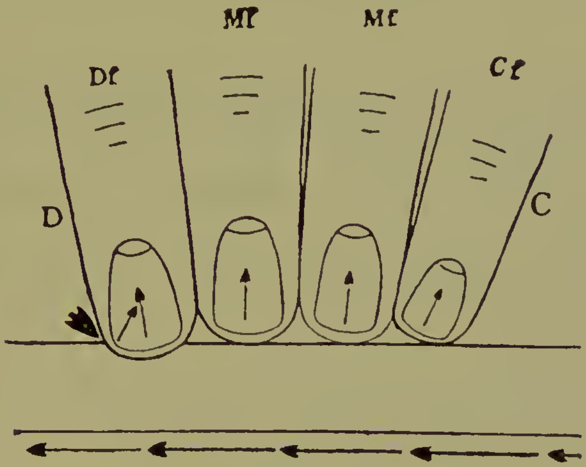


Pressure i : A light ictus strikes each finger in succession; the wave is felt moving.

Experiment XIV.

If pressure ii be employed, the sensation of ictus will be perceived mainly at the distal border of *Df*,

FIG. 57.



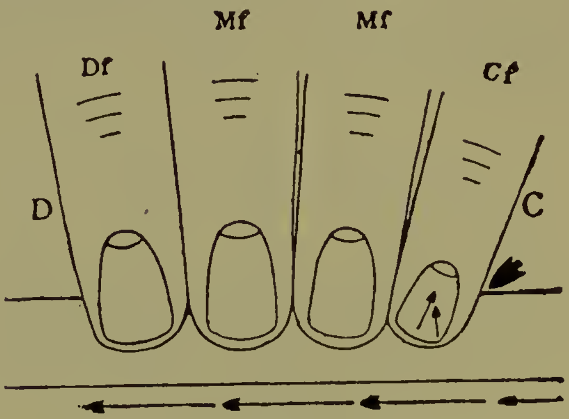
Pressure ii applied by *Df* only, pressure i by the rest : The localisation of the ictus is the same as when pressure ii is made by all.

the other fingers receiving a relatively slight and indistinct shock. As shown in Fig. 57, the same incidence of the ictus is observed when *Df* only is exercising pressure ii, the other fingers using pressure i.

Experiment XV.

The results obtained with pressure iv are analogous to those previously described. *Cf* alone is the seat of sensation.

FIG. 58.



Pressure iv: Ictus and lift felt exclusively at *Cf*.

In general it may be stated that the greater the number of fingers used—(1) the greater will be the duration of the total impression, beginning at the proximal finger with the onset of the wave and ending at the distal finger with the ictus; (2) the more distinct also will be the feeling of progression of the wave; and (3) the stronger also will be the sensation of upheaval of the artery.

Since, however, the difficulty of producing even pressures at all points grows with the number of fingers employed, the variety in the site of the maximum impulse will be greater, and the ictus may appear to be a shifting quantity. To take only one instance, if the intermediate finger be pressed more firmly than the extremes, the ictus will be localised under this finger, with varying results in respect of the two others according to the degree of the pressures made by them.

CHAPTER VII.

THE PROXIMAL, THE DISTAL, AND THE INTERMEDIATE ICTUS. THEIR DIRECTION AND RELATIVE TIME.

The Directions from which the Ictus is felt to arise.

From the way in which it strikes different parts of the finger under different degrees of pressure, the wave might be expected to convey an impression of varying directions. Thus, in cases when pressure i or pressure iii was employed, the ictus would be felt to strike *upwards*. In the case of pressure ii it would strike *backwards*, as though coming from the hand. In that of pressure iv the stroke would possess a *forward* direction as though coming from the heart. These are precisely the sensations experienced.

With a view to identifying the various directions described, we propose to adopt the following terms: *proximal ictus*; *distal ictus*; and *intermediate ictus*; these terms not implying of necessity an identity in the nature or mechanism of the events.

Analysis of the Proximal Ictus.

Without anticipating remarks which belong to another section (see page 304), attention may be called to the contrast which exists between the proximal ictus and the other varieties. The intermediate ictus will be found not infrequently associated with the distal ictus, but seldom, if ever, with the proximal ictus; whilst proximal and distal ictus are absolutely opposed.

Its Constituent Elements.

The question as to the mechanism of the distal ictus has not yet been answered, but we may form some idea as to the mechanism of the proximal ictus.

A finger, firmly planted down across the artery, must clearly receive the shock of the head of the wave, of the body of the wave, and of any ictus the wave may possess. For these constituent elements we are entitled to search the proximal ictus, and in favourable instances we shall identify them all three. *The onset* of the wave constitutes in itself a miniature ictus; in some cases it may even acquire the full value of the latter as regards strength and suddenness. It can in most pulses be distinctly felt striking against the finger. In its train comes the growing fulness of *the wave.* Both these preliminary events are of brief though appreciable duration, and owing to their relative softness, apt to be overlooked, or to be regarded as early phases of *the ictus strictly so called.* The latter is the prominent event, though a peculiarly short one.

Great Abruptness of the Ictus Proper.

It is noteworthy that although the ictus strikes up against the finger, its pressure is evanescent: the blow is instantaneous, and falls away from the finger with singular suddenness. This abrupt ending contrasts with the feeling perceived in Experiment C, a feeling more substantial and lasting, the ictus seeming not only to strike the finger but to pass under it.

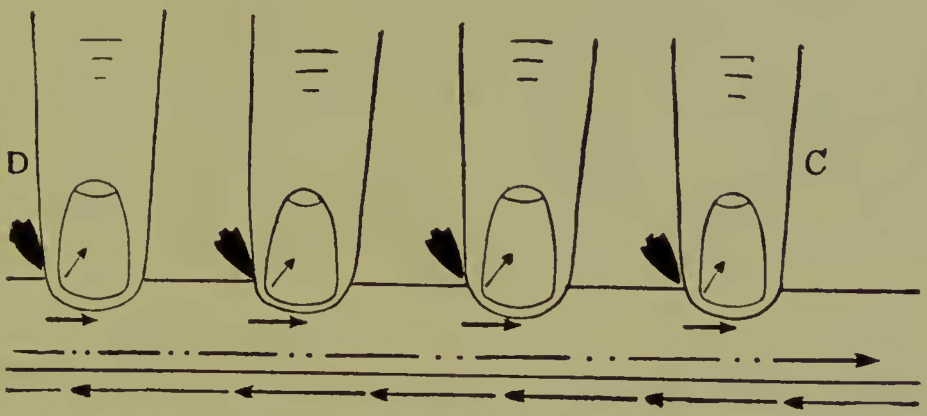
Though the two minor impacts associated with the proximal ictus lack this abruptness, and keep up their pressure for an appreciable time, the instantaneous character special to the ictus itself becomes the distinctive feature of the proximal pulsation as as a whole, a feature sufficiently marked to cause us to regard this ictus as differing from the two others. Between the latter we may possibly find similar distinctions, when their respective mechanisms shall stand forth as clearly as that of the proximal ictus.

The Direction of the Ictus.

The ubiquitous occurrence and the varying delay of the ictus point to it as a travelling event, or, at any rate, as being associated with some travelling event. At the wrist the direction which it naturally assumes is *centripetal.* This statement is borne out by the simple experiment detailed on page 156.

But the simplest demonstration of this fact lies in the inspection of an arm presenting at the wrist and at the elbow a strong visible pulse beat. Instrumental methods might be adopted for timing the two events, and for supplying written evidence of their time difference. They could hardly add anything to the clearness with which the finger perceives the latter. Palpation of the artery, inch by inch up the arm, proves conclusively the identity and the continuity of the ictus which is observed at different moments at the two extreme points. The delay at the elbow must therefore be admitted as evidence that the ictus has travelled upwards from the wrist (*cf.* p. 322).

FIG. 59.



The finger is gradually shifted up the arm : the same ictus follows it up. This proves the identity of the ictus felt first at the wrist and later at the elbow.

The Relative Time of the Ictus.

The impression that the tactile ictus is coincident and perhaps identical with the so-called percussion-wave is one difficult to resist. At this early stage of the study of the tactile phenomena, we should, however, avoid nothing more carefully than prejudging the points at issue.

Beyond doubt, in all arteries the ictus follows very quickly upon the *onset* of the systolic wave ; but it has perhaps never been noticed that the interval of time between them is not everywhere identical. This unexpected fact may be observed in the radial artery, even within the short stretch of three inches where it is visible at the wrist. The differential delay is very small; but it is not too small for the eye or for the finger. The ictus will be seen to take place appreciably earlier after the onset of the wave at the extremity of the radius than a little higher up; and the same conclusion will be arrived at by the trained observer, if he will apply the full length of the thumb, or three finger-tips to the same region.

How to Determine the Relative Time of the Ictus.

Two methods are at our disposal in estimating the relative time of the ictus at different parts: the tactile and the ocular method. Their respective value will be discussed at another place.* The touch and the eye have often to combine in work; but it is possible to use them separately in this case.

The rapid rate of the events and the minuteness of any time-differences between their incidence at various spots almost baffle observation. Among the chief difficulties is that of keeping separate the sensation of the advent of the wave, and of the ictus respectively. The wave, being of course perceived first by the proximal finger, would almost inevitably cause the ictus to be felt first by this finger, although the two events do not of necessity keep parallel times or necessarily agree in direction. In most visible pulses the *wave* is not seen: we are therefore able to eliminate this possible source of fallacy by using the visual method. If we watch the pulse at the wrist without applying the finger, we shall generally be able to perceive a minute difference between the time of onset of the ictus at the two extreme spots where it may be visible, and we shall recognise that it is the distal spot which shows the earlier ictus (see also p. 322).

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* Observers vary greatly as to their capacity for timing their sensations. Considerable practice is required even by those who are excellent "timists." It is important that any isolated experiments of one individual should be confirmed by a majority of other observers.

We might substitute for the pressure of the finger that of a glass slide applied across the long axis of the artery; this would allow us to apply pressure and at the same time to keep simultaneously within sight the artery on either side of the pressure applied. It will be found that more pulsation occurs when pressure is made, and that the distal beat at the same time is delayed.

Timing the Pulse with the Foot.

The difficult task is much facilitated by the capacity which we possess of beating strictly accurate time to events occurring at regular intervals. In this case the personal factor and the time of nerve conduction are eliminated. Our movements in beating time anticipate our perception of the rhythmic events, and can be made perfectly synchronous with the latter.

Thus in comparing the time of the distal and of the proximal ictus, we first beat with the foot accurate time to the distal ictus (obtained by using pressure ii, *cf.* p. 115). Whilst we continue to beat time, pressure iv is made by the finger : this will elicit the proximal ictus. We are now in a position to notice any want of synchronism between the beat of the foot, which represents the distal ictus, and the proximal ictus which is felt or seen.

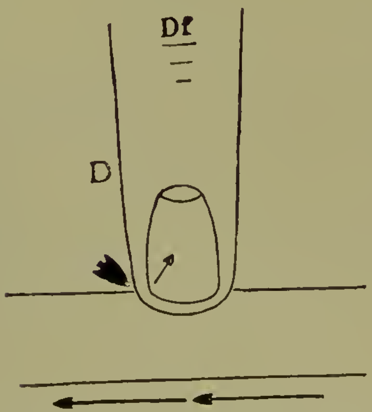
It is well to verify the continued accuracy of the foot beat by relaxing the pressure so as to restore the distal ictus. In this way we can acquire proof that the distal ictus is *not absolutely synchronous* with the proximal. My own determinations have convinced me that it is an earlier event than the latter.

Practical Determination of the Relative Time of the Distal and of the Proximal Ictus.

There are various ways of comparing the time of the two events ;

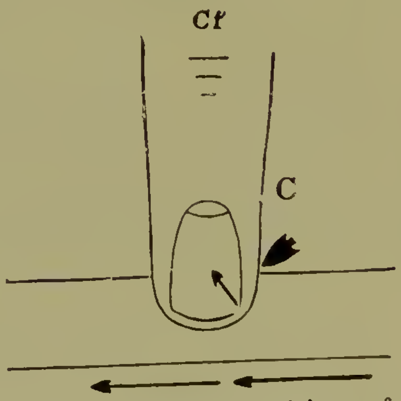
Experiment XVI.

FIG. 60.



A. First position of finger. The foot times this ictus.

FIG. 61.



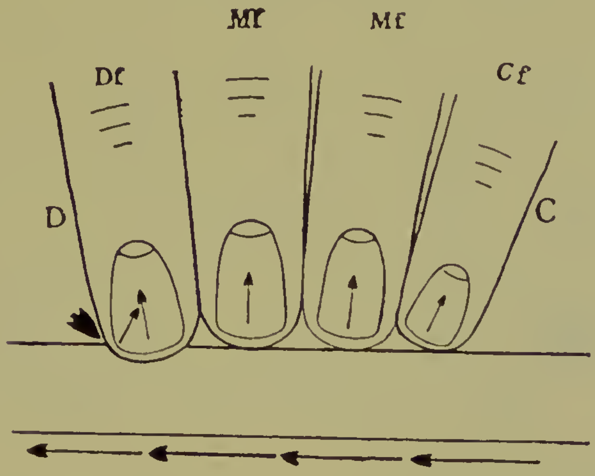
B. Second position of finger. The foot keeps up the time of A.

1. By using one finger and ascertaining the rhythm of the distal ictus at *D*. The rhythm being meanwhile kept up by the foot, pressure iv is applied. The proximal ictus then appearing at *C* will be fractionally later.

Experiment XVII.

2. By using four fingers as already described on p. 143. The distance being increased, it will become less difficult to identify the delay. In a slow pulse this method will give very satisfactory results.

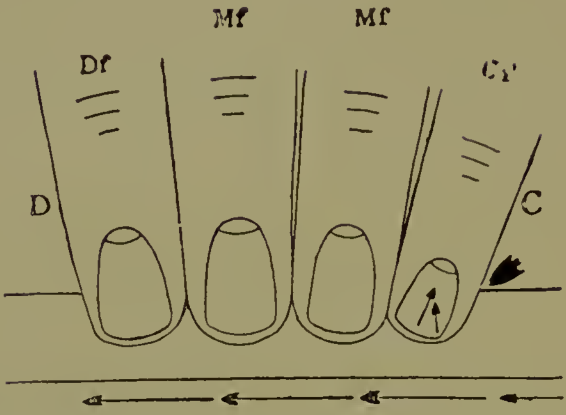
FIG. 62.



A. First position. The foot beats time to the distal ictus.

As shown in the figure, in the first phase of the experiment the index finger alone need be depressed to obtain the distal ictus. This will also be the most satisfactory beat to time with the foot.

FIG. 63.

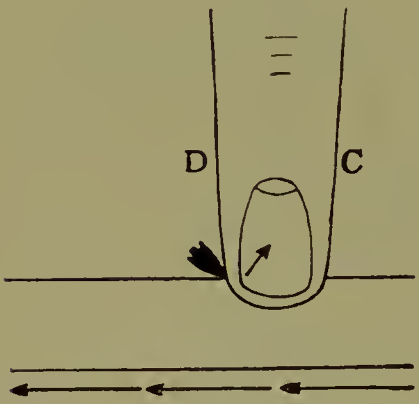


B. Second position. The proximal ictus is obtained, whilst the rhythm of A is kept up by the foot.

Experiment XVIII.

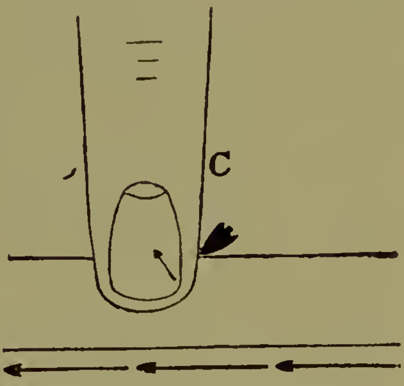
3. Lastly, by using both arms* of the patient and applying a finger at the same level to each with pressures ii and iv respectively.

FIG. 64.



A. The distal ictus, obtained in the right arm.

FIG. 65.



B. The proximal ictus, obtained in the left arm.

The distal ictus—in this figure the right—will be easily recognised as the earlier of the two.

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[*] In all comparative time-observations made in both arms, an essential preliminary is to ascertain the synchronism of the two radial beats, and their freedom from anastomotic pulsation.

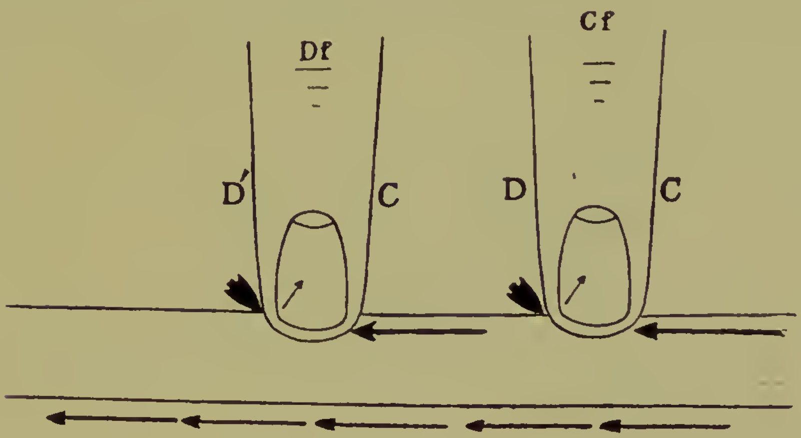
If any doubt should be felt, the observation should be repeated with a change of hands; or the respective pressures may be shifted from one arm to the other.

Combined Observation of the Progress of the Wave and of the Progress of the Ictus.

It is good practice for educating the timing capacity of the finger to watch the full succession of events.

Experiment XIX.

FIG. 66.



Pressure ii applied by both fingers. *Df* is struck later by the systolic wave, but earlier by the ictus, than *Cf.*

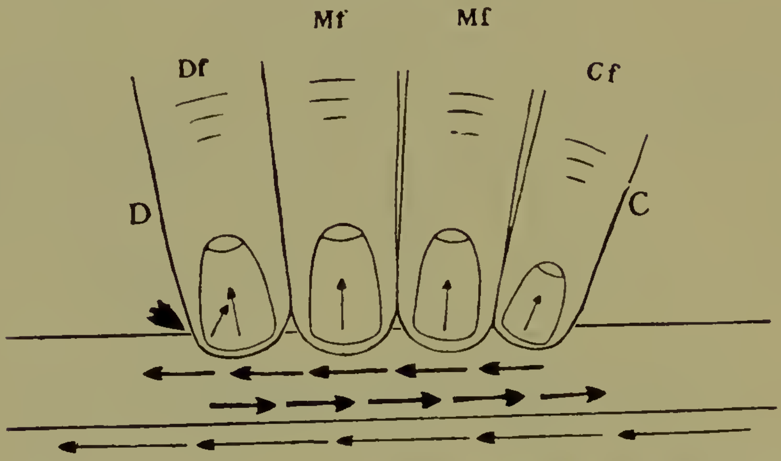
When two fingers, placed on the radial at a short interval, both exert pressure ii, sufficiently lightly to enable the onset of the wave to be felt by each, whilst the distal ictus is still plainly perceptible, the direction followed by the wave from *Cf* to *Df* will be quite unmistakeable. In other words, *Cf* will be struck by the wave perceptibly earlier than *Df.* Yet if the attention be concentrated on the distal ictus, it will be found that *D′* is earlier than *D*.

This latter observation is a little difficult to carry out.

Experiment XX.

An easier way for the observer to demonstrate for himself the retrograde progress of the distal ictus is to place the four fingers of the left hand in a group on his right radial artery, pressure ii being lightly applied. The ictus will strike the fore-finger *Df* first, and strongly.

FIG 67.



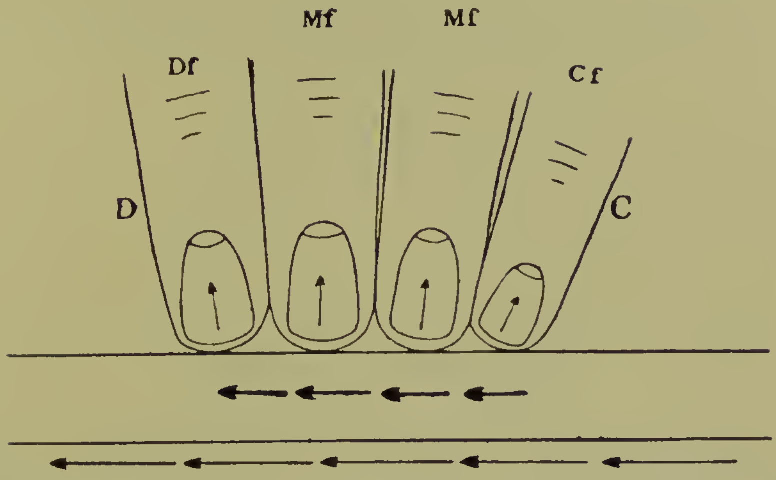
Pressure ii applied by the observer to his own arm. The systolic wave is felt *descending* towards the wrist, the distal ictus *ascending*.

It will not, however, stop there; but, if the pulse be sufficiently strong, and the finger pressure appropriate, it will be felt in succession by the middle finger and by the ring finger.

Experiment XXI.

Four fingers may also be used to study the progress of the wave. If pressure i be employed,

FIG. 68.



The downward march of the wave recognised with pressure i.

the onset of the wave will be felt in a centrifugal direction, as shown by the arrows, first by the little finger *Cf*, and seriatim by the others.

CHAPTER VIII.

MODIFICATIONS OF THE PULSE CAUSED BY COMPRESSION OF THE ARTERY, OR INDUCED BY POSTURE.

I. The Effect of Obliterating the Pulse at the Wrist, on the Strength of the Ictus above the Block.

Experiment XXII.

If whilst pressure ii is kept up by the proximal finger *Cf*, a distal finger *Df* be placed farther down upon the artery, the effect will be to make the pulsation at *Cf* stronger ; and this will be strongest if *Df* be applied forcibly so as to compress the artery.* This fact will be easily recognised by alternately lifting and pressing down *Df*. At each pressure by the finger almost a shock is felt at the distal border of *Cf*, so decided and distinct is the impression.

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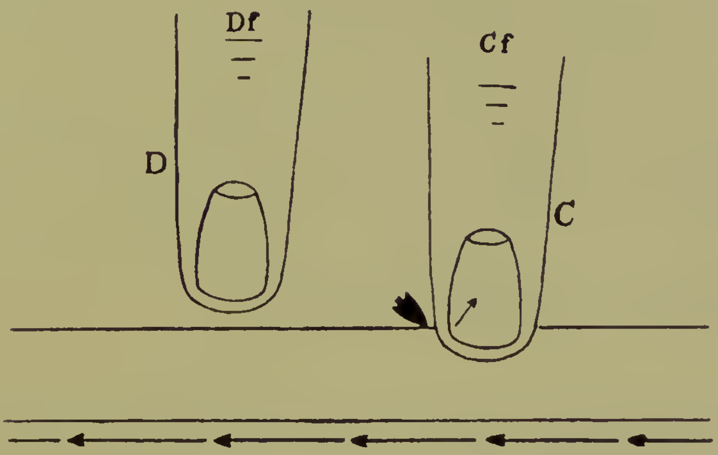
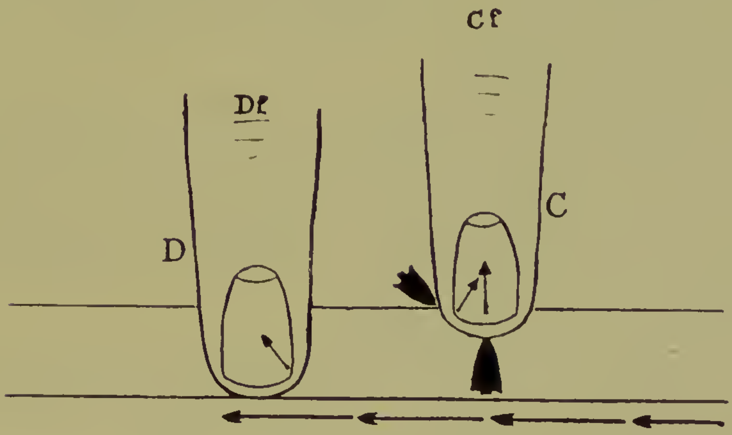
* This observation is identical with that described by Dr. G. Oliver, which the author had the pleasure of reading in *The Practitioner* (vol. 50, April 1893), a year after the above was written. Further reference will be made to Dr. Oliver's interesting experiments and results. The term "expansile reaction," which applies to one phase of this observation, is a useful one.

FIG. 69.



A. Distal ictus at *Cf*. (*Df* is not applied.)

FIG. 70.



B. *Df* being firmly applied, the pulsation at *Cf* is much increased.

It may even be said that the pulsation continues to be intensified by each successive increment of pressure until *Df* produces obliteration.

Marey * long ago described, in the following words, the same phenomenon, observed by means of the Sphygmograph:

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* E. J. Marey : "La Circulation du Sang a l'État Physiologique et dans les Maladies," Paris, 1881.

> "Si l'on comprime graduellement l'artère au-dessous du sphygmographe, au niveau de l'articulation radio-carpienne, on constate un accroissement de l'amplitude des pulsations. La figure 159 donne un bon example de cet accroissement de la force du pouls; on doit l'expliquer par le choc de l'onde sanguine contre l'obstacle sur lequel elle se réfléchit comme une vague qui vient butter contre un rocher. C'est cet effet que nous avons déjà indiqué sous le nom de coup de bélier, empruntant aux hydrauliciens une expression technique."

In this connection it is interesting to note von Frey's statement, that he has demonstrated, by repeated experiment, that the obliteration beyond the sphygmograph of the radial or of any other artery, introduces no essential alteration into the shape of the tracing.

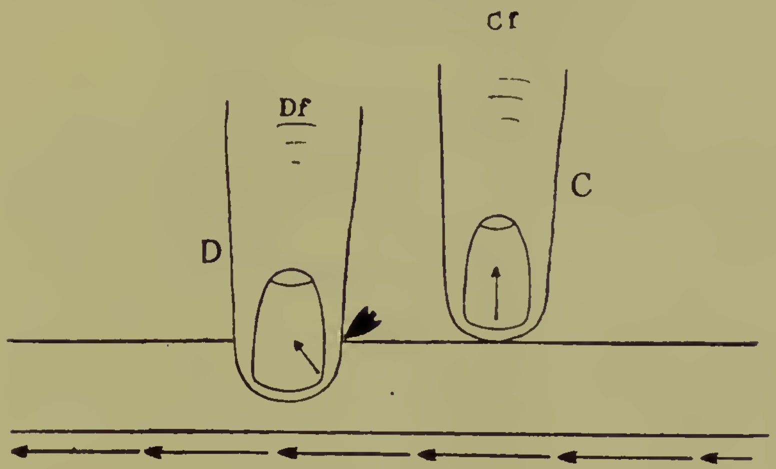
The experiment described above is most instructive in connection with the proximal ictus also. Reference has elsewhere been made (page 122) to the observations obtained with the proximal border of the single finger employed.

The increased volume of the ictus is not, however, to be duly appreciated by one finger. Indeed, it has already been pointed out that if the pressure be very great the sensation of proximal ictus may be totally abolished. The following experiment is based upon this peculiarity.

Experiment XXIII.

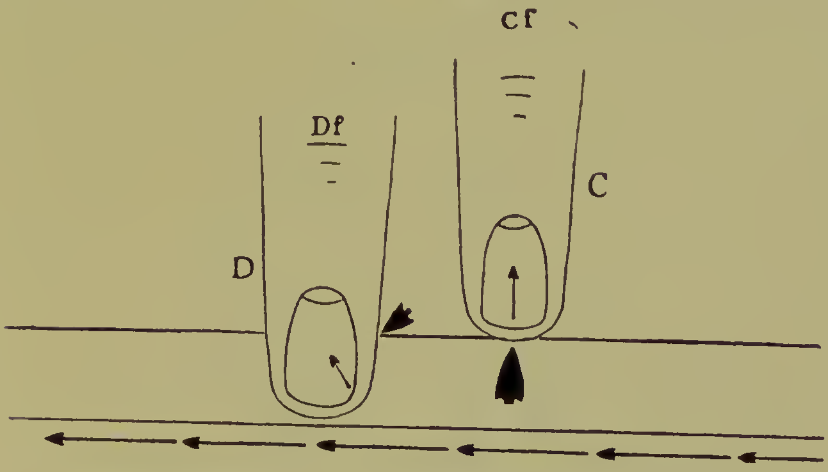
A curious result may be obtained under favourable circumstances. The finger pressures may be so arranged that no pulse is perceptible (A) at *Cf* except when *Df* is firmly applied (B).

FIG. 71.



A. *Cf* so lightly applied that it perceives no pulse, whilst moderate pressure is made at *D*.

FIG. 72.

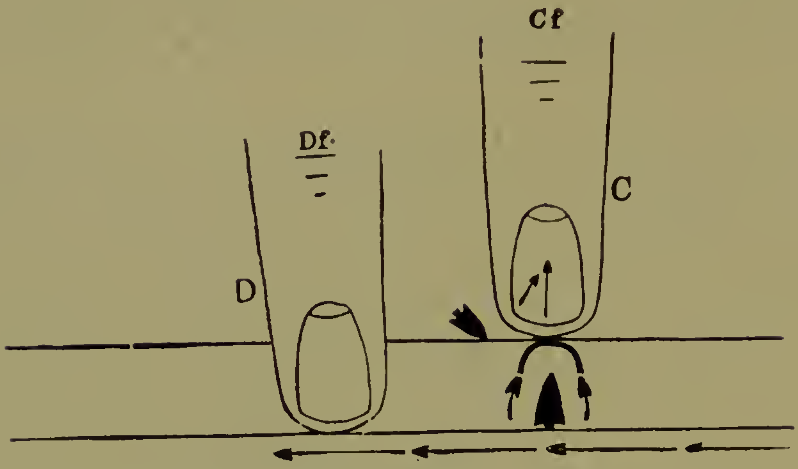


B. Stronger pressure by *Df* causes pulsation to be felt by *Cf*.

During this second phase (B), both fingers perceive the ictus; but if *Df* be pressed down very strongly, it may in turn lose the feeling of pulsation (C).

In this way *Cf* and *Df* would alternately perceive pulsation, and cease to perceive it.

FIG. 73.

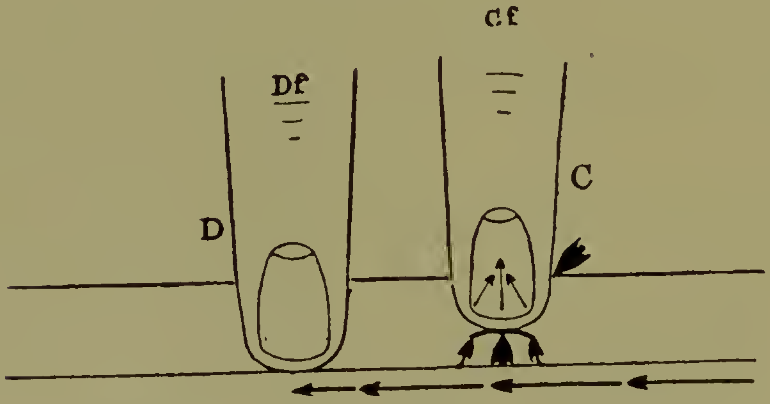


C. Forcible pressure deprives *Df* of the sensation of ictus. Ictus further intensified at *Cf.*

Experiment XXIV.

Analogous results are obtained when *Cf* is brought down upon the artery, with pressure iii or iv, just

FIG. 74.



D. The same increase in pulsation obtained when *Cf* exerts pressure iii or iv.

above the seat of obliteration. The volume of the pulsation will be much increased whenever *Df* makes pressure; and, with pressure iv, this increase will concern the proximal ictus (see Fig. 74).

The Effect of Forcible Pressure on the Artery and on the Pulsation above the Seat of Pressure.

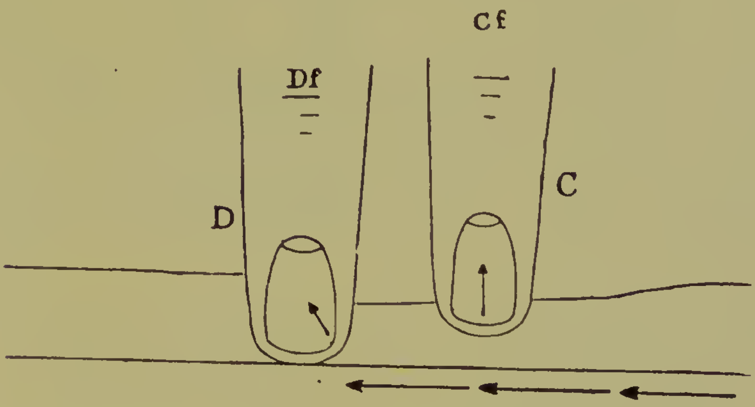
The arrangement of fingers described above enables us to recognise a further influence beyond the merely mechanical alteration of the intra-arterial current and pulsation due to distal obliteration.

Factitious Arterial Spasm and Paralysis.

Experiment XXV.

Obliteration having been effected by moderate pressure, with the result of calling forth the expansile reaction, if sudden and hard pressure be now made upon the artery, the volume of the pulsation under *Cf* will quickly diminish, till it almost ceases to be felt.

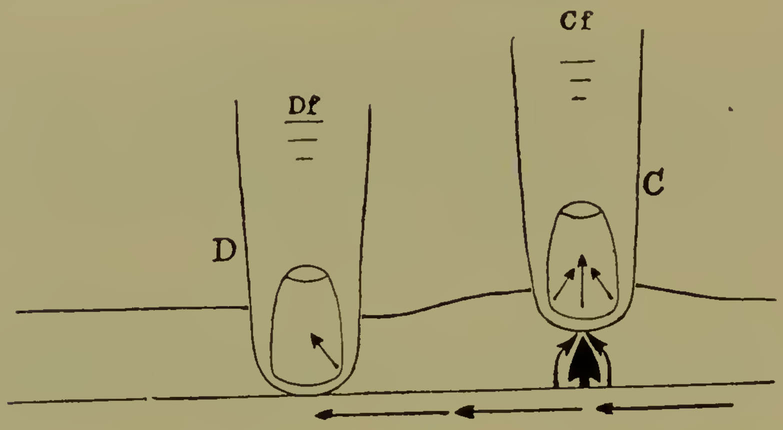
FIG. 75.



Sensation of diminished volume and pulsation of artery at *Cf* when forcible pressure is made by *Df* suddenly.

If the same pressure be kept up,—after a varying number of seconds, the pulsation will gradually return, and ultimately assume greater proportions than previously.

FIG. 76.



Pulsation returning after a while at *Cf*, during persistence of pressure at *Df*.

This is a practical illustration of Marey's law,* that moderate stimulation will produce arterial contraction, and excessive stimulation will eventually produce dilatation. In this case the immediate effect is arterial spasm, which quickly gives way to paralysis under the influence of a continuance of the severe stimulation. We witness here the results of that which may be termed the traumatic degree of pressure.

Just as a direct lesion of an exposed artery causes it to contract, the powerful pressure applied through the skin stimulates the muscular coat of the artery to spasmodic contraction.

We are thus in possession of a means of causing arterial muscular spasm, and of studying the duration of the spasm, and some of its features.

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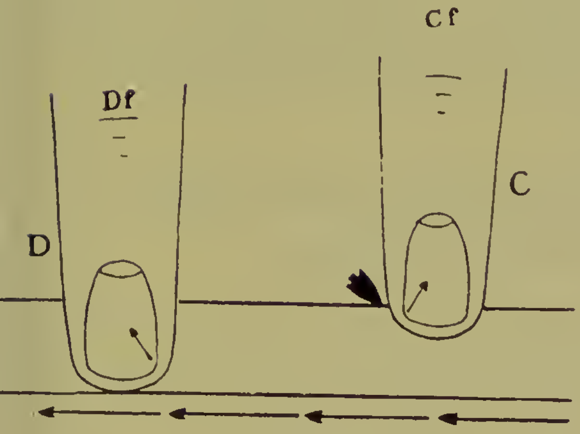
* Marey, "Mém. sur la Contractilité Vasc." (*Ann. des Sc. Nat.* 1858, 4^{me} Série, t. ix. p. 69).

The permanently exaggerated pulsation which follows upon the local occurrence of spasm may be regarded as a species of paralytic relaxation of the arterial muscular tone, induced as a result of the previous stimulation of the muscular fibres.

The Effect of Obliterating the Pulse at the Wrist, on the Time of the Ictus above the Obliteration.

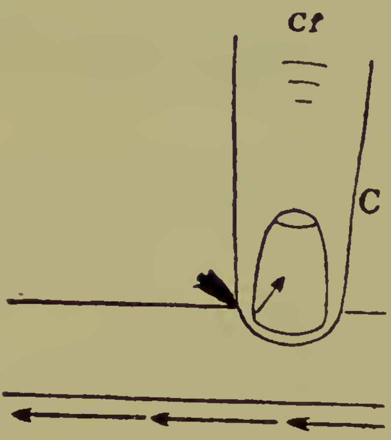
Experiment XXVI.

FIG. 77.



A. Right arm. Obliteration at *Df* causes the ictus at *Cf* to be earlier.

FIG. 78.



B. Left arm. Pulse not blocked. The ictus at *Cf* used as a standard of time for (A).

The easiest way of trying this experiment is to use the patient's two arms. In one of them *Df* is applied with obliterating pressure close to the wrist; and *Cf* is lightly applied higher up the arm.

In the other arm, *Cf*, is applied in a situation, and with a pressure, identical with those employed for *Cf*; but distal pressure is not made.

This arrangement enables the trained observer to realise that distal obliteration causes a slight advance in the moment at which the distal ictus is felt by the proximal finger.

II. Changes in the Tactile Pulse induced by Posture.

This influence on the pulse has been studied long ago from the point of view of rate. Recently, Dr. Oliver (*Practitioner*, February to August, 1893) has investigated the effects on the pulse of changes in the posture of the body in connection with the "expansile reaction." An analysis of this portion of his important observations cannot be attempted here.

Influence of the Attitude of the Arm on the Strength of the Pulse Wave.

There is, however, a question almost more closely connected with everyday clinical work,—that of the variations noticed in the radial pulse, according as the arm is raised or depressed.

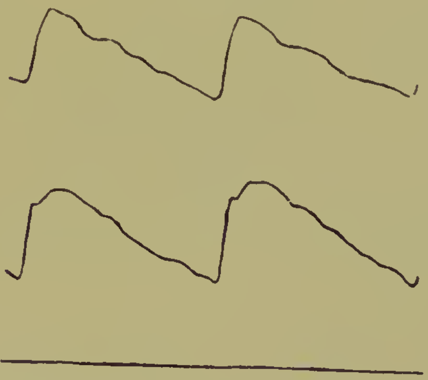
Experiment XXVII.

Marey (*loc. cit.* p. 287) deals with the subject in the following terms:

"Quand on tient le bras en élévation, on observe souvent que le pouls y devient plus fort. C'est que l'artère, trop peu dépressible dans l'état normal le devient davantage quand l'élévation a fait baisser la pression sanguine dans le vaisseau. Dans ce cas, l'ondée sanguine s'élance avec plus de force dans l'artère moins tendue, et la variation de pression qu'elle y produit est plus brusque. Lépine et Lorain ont constaté cet effet et ont souvent utilisé, au lit du malade, cette manière de rendre plus apparent un pouls trop faible pour être fidèlement inscrit, etc."

Von Kries (*loc. cit.*, pp. 103–111), devotes much attention to the investigation of this remarkable phenomenon. His observations will form the subject of further remarks in Part IV. (see p. 231) in connection with a study of its mechanism. According to him, the increase in volume described by Marey is not the only change brought about in the radial pulse by elevation of the arm. The additional differences which he notices will be gathered from an inspection of the accompanying sphygmogram which is reproduced from von Frey's work.

FIG. 79.



Radial tracings reproduced from von Frey (*loc. cit.* p. 220). The upper tracing taken with arm dependent, the lower tracing with arm raised.

In the tracing corresponding to the elevated position, the line of ascent is more oblique in its upper part, and distinctly anacrotic, the line of descent very slow in its fall, and the dicrotic notch and rise both very shallow.

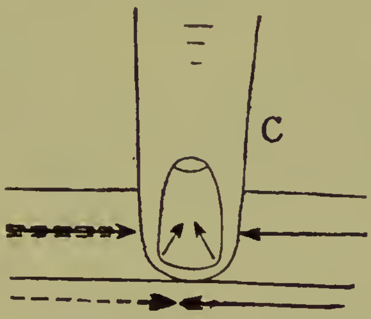
All these features may not be separately perceived, but they are readily recognised, as a whole, by the finger. The pulse assumes the type with which we are familiar in cases of mitral and of aortic stenosis.

CHAPTER IX.

THE ELEMENTARY STUDY OF THE ANASTOMOTIC PULSE.

THE complications which arise when an anastomotic wave is combined with the ordinary wave, have hitherto obliged us altogether to exclude the former from consideration. We now turn to its study.

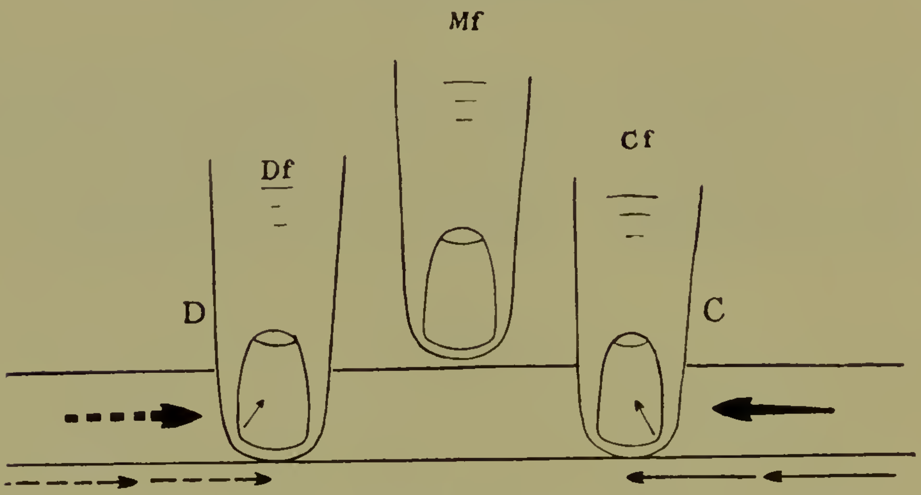
FIG. 80.



Obliteration by one finger. The interrupted arrows represent the anastomotic blood-stream and pulsation.

In many radial pulses, probably at times in all, the pulse wave finds its way round the palmar arch, through one vessel or the other; most often, it is stated, through the *Superficialis Volæ.* As explained above, the presence of this additional pulsation may be detected by a single finger, if sufficiently sensitive, by pressing so firmly against the radius as to obliterate the arterial channel. Any pulse perceived by the distal side of the finger can then be only an anastomotic and recurrent pulse. It is much easier, however, to obliterate the artery with one finger *Cf*, and to feel the anastomotic pulse with another finger *Df*, applied farther down the wrist. This is a method which was described by Ozanam, and separately by Dr. Douglas Powell (see Fig. 81).

FIG. 81.



Obliteration by two separate fingers. Their pulseless interval may be tested by *Mf*.

If we keep the artery obliterated conveniently high in the wrist, we secure room for further manipulations, and freedom from interference on the part of the normal wave. In this way we shall find that in every respect, except in its direction, which is centripetal, and in its strength, which is reduced, the anastomotic pulse is analogous to the ordinary uncomplicated pulse; and that it behaves according to the same rules; so that with eyes shut and the patient's arm duly covered, we might be mistaken as to the kind of pulse felt. The observations detailed

CHIRURGICAL

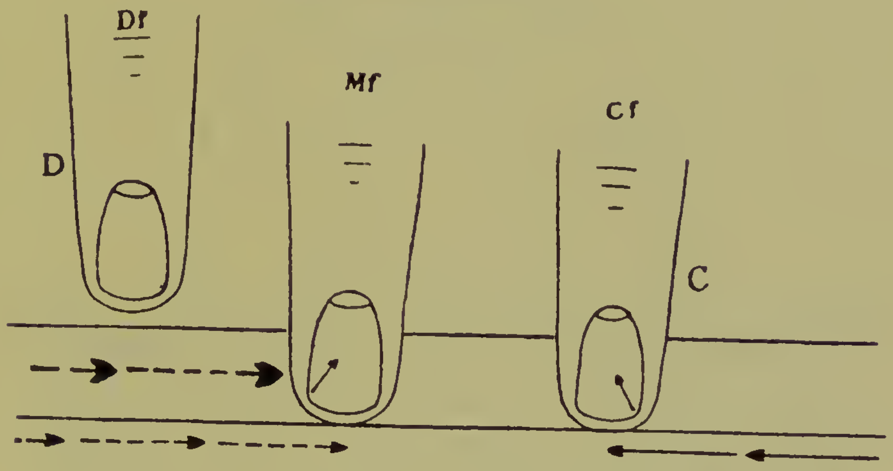
in connection with the ordinary pulse apply to the anastomotic, almost without any alteration, as will be gathered from the diagrams, which represent in each case results obtained by direct experiment.

The Progress of the Anastomotic Wave.

Experiment XXVIII.

The recurrent direction of the wave is easily demonstrated by using three fingers. *Cf* stops the direct wave above; *Df*, below, alternately sets free and stops the anastomotic wave; and *Mf* likewise alternately receives and loses the sensation of ictus.

FIG. 82.



Other mode of demonstration of the direction of the anastomotic wave. *Df* alternately interposes between *Mf* and the wave, or allows the wave to strike.

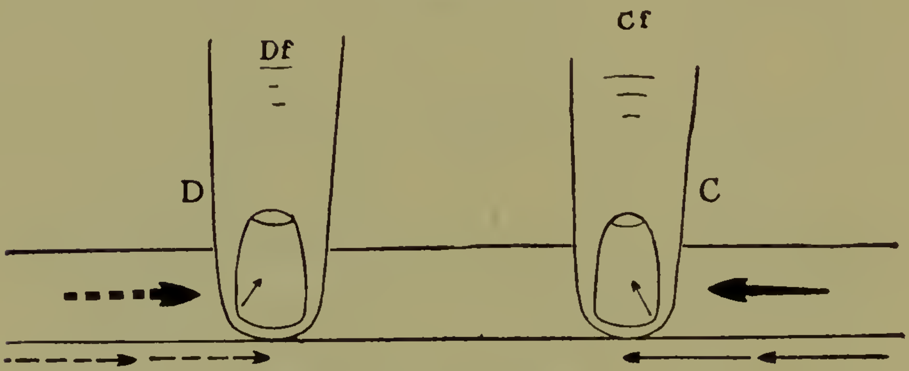
The instant *Df* is raised the wave strikes the finger *Mf* on its distal border. The instant *Df* is depressed *Mf* is once more deprived of all pulse sensations. Meanwhile, *Cf* being hard down on the radius, no pulse can reach *Mf* from above, and the pulsation felt by it is obviously anastomotic, being conveyed through a collateral channel from the ulnar artery.

The Relative Time of the Anastomotic Wave at the Wrist.

The longer route taken by the anastomotic wave inevitably causes its arrival at the wrist to be later than that of the direct wave. This delay is sometimes, though not readily, perceived by the touch.

Experiment XXIX.

FIG. 83.



Whilst the arrival of the direct wave at *C* is being timed by the beat of the foot, when *Df* is raised (see Fig. 84), *Cf* feels the arrival of the anastomotic wave as a later event.

Let the two fingers *Cf* and *Df* be applied at a slight distance from each other with obliterating pressure. The direct wave * will strike the proximal side of *Cf*; and the anastomotic wave, the distal side of *Df*.

The second stroke will be, often appreciably, later than the first.

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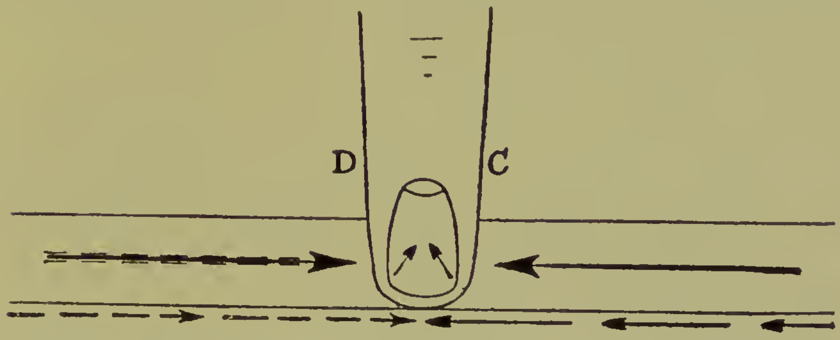
* For further comment on this, see Part V., p. 305.

Another method consists in observing the time of the ordinary pulse at *Cf* (the finger used as block); timing its beat with the foot, and, after making sure of the rhythm, letting loose the anastomotic wave at *Df*: the distal pulsation, immediately felt at *Cf*, will be unmistakably later than the stroke of the foot.

We shall see that there is reason to believe that the transmission of the ictus along the palmar circuit is slower than the transmission of the ictus backwards up the arm (see p. 347).

Experiment XXX.

FIG. 84.

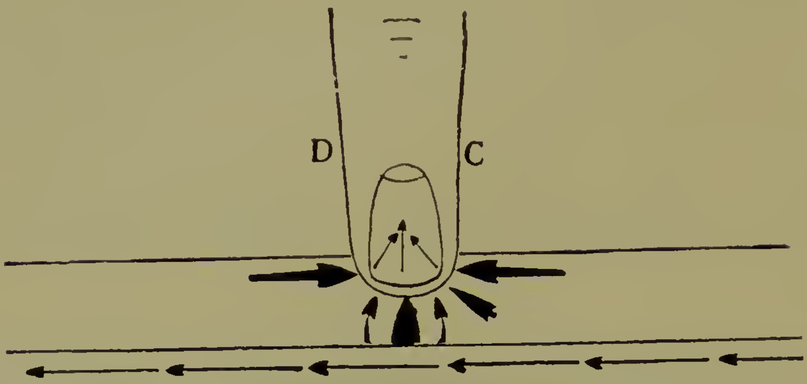


One finger, carefully applied, distinguishes a delay between the two waves striking its opposite sides.

The same interval in time may be perceived with the help of one finger, as shown by the diagram.

In the same way, if the finger be applied firmly enough (pressure iii) to obtain the sensation of intermediate beat, this sensation will not be a simple stroke, as with each of the two fingers previously used, but a more prolonged feeling, made up of the sensations corresponding to each of the four degrees of pressure (see Fig. 85).

FIG. 85.



The sensation of intermediate ictus analysed into a succession of sensations striking the sides and the tip of the finger.

Variability of the Delay.

In different individuals the delay of the anastomotic wave will vary much. It may sometimes be less with a slow than with a quick pulse rate.

In old people, and in cases of arterial rigidity, or when tension is high, it will be much shorter than in young subjects with elastic arteries, or in those presenting low pulse tension.

We may therefore expect the interval to vary in the same individuals with the state of the circulation.

Experiment XXXI.

Since raising the arms diminishes arterial fulness, we may expect a retardation of the anastomotic wave from this cause. If the patient's arm be fully raised, the anastomotic wave will be noticeably delayed; if it be lowered from the level of the bed to the floor, the wave will become decidedly quicker than in the horizontal position.

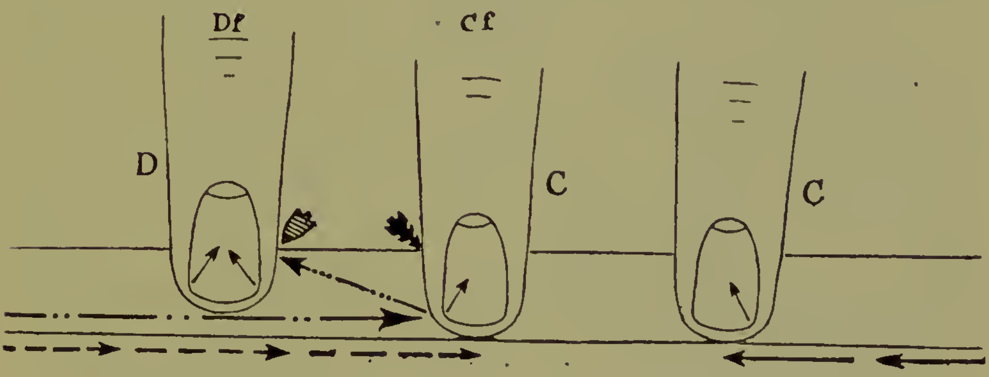
THE ANASTOMOTIC ICTUS.

Hitherto we have spoken of the anastomotic wave and of the time of its impact. Pursuing the analogy which exists between this wave and the direct wave, we now turn our attention to the ictus properly so called.

Experiment XXXII.

When the pressure of the blocking finger *Df* is slightly relaxed, the anastomotic wave, which previously was stopped by that finger, not only strikes *Cf*, but, if the pressure of *Df* be suitably adjusted, it will also cause an ictus to be felt at the heart-side of *Df*.

FIG. 86.



After striking *Cf*, the anastomotic wave is received by the proximal side of *Df*.

This experiment possesses, it will be seen, much physiological importance. The anastomotic ictus is analogous to that which has been described as the distal ictus of the ordinary pulse (see p. 114), although now it occurs on the reverse side.

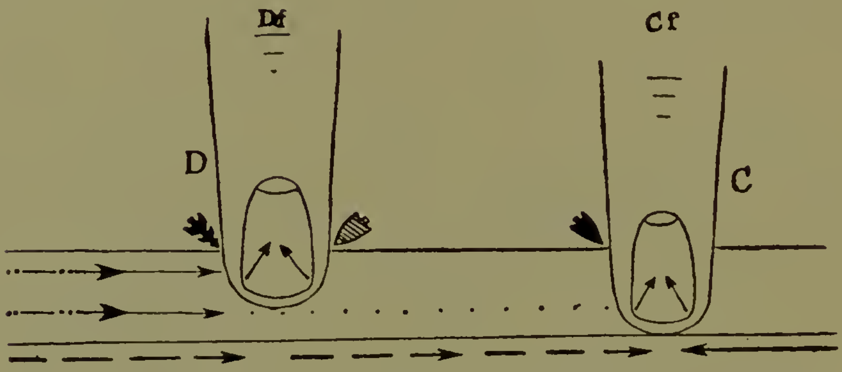
The Relative Time of the Anastomotic Ictus.

It was noticed (see p. 152), in connection with the ordinary proximal ictus, that this occurred fractionally later than the distal ictus. Here in like manner the anastomotic ictus should be earlier at *Cf* than it is at *Df* (see Fig. 86).

Experiment XXXIII.

This could be easily verified by the two fingers applied in the same manner as in the preceding experiment, by varying the pressure of *Df*.

FIG. 87.



The anastomotic ictus, travelling upwards, and striking in succession *Df*, *Cf* (which is used as block), and *Df* again.

N.B. The distinction between the wave-onset and the ictus, indicated in the figure, will be dwelt on at p. 305.

The ictus felt at *Cf* is indeed bound up with the anastomotic wave, propagated past *Df*, and which makes, at the moment of its passage under that finger, a slight impression on the distal side of *Df*. The two arrow-heads at *Df* represent the two events occurring on opposite sides of that finger. With sufficient attention it may be possible to realise both sensations, and to notice that the distal sensation (at D) is an earlier event than the ictus felt on the proximal side of *Df.*

In a boy, *æt.* 9½, it was very plain that, whilst the distal finger was pressed down moderately (say half-way through the diameter of the artery), the proximal finger being meanwhile employed in obliterating the channel, *Df* felt the ictus on the side nearest the heart. But when the pressure was increased, so as to obliterate the artery at *Df,* then the ictus was felt only on the wrist side of the said finger. In a previous experiment performed in a strong man, the ictus on the proximal side of *Df* was distinctly later than that felt on the distal side of *Cf,* the interval of time being of course minute.

This accordance, in spite of reversed directions, with the observations made on the direct pulse, is strongly confirmatory of the correctness of previous results. The mechanism of the ictus in both cases would, judging from analogy, be the same. It will be discussed later.

For the present let it be stated that, as regards the ictus, the anastomotic wave behaves in the same manner as an ordinary descending wave; but that, as might have been expected, the pressures necessary in order to alter the site of the ictus and to obliterate the pulse are less than is the case with the ordinary pulse.

THE ANASTOMOTIC THRILL.

Another set of observations especially connected with the anastomotic pulse claims attention at this place.

Experiment XXXIV.

Since, by varying the pressure of the blocking finger *Cf*, we can either obliterate the pulse or reduce it to any extent, the artificial equalisation of the main pulse and of the anastomotic pulse in the length of artery included between *Df* and *Cf*, would be merely a question of adjustment. Supposing this to have been carried out, what would be the effect produced at *Cf*? The equalised waves would mutually destroy their velocities, whilst the pressures would add up. Owing, however, to the slight difference in the time of their transmission, the waves would not overlap with perfect symmetry, but the two summits, and any sets of points corresponding in their level in the two waves, would alternate with each other. The result might be a thrill such as depicted in the diagram.

FIG. 88.

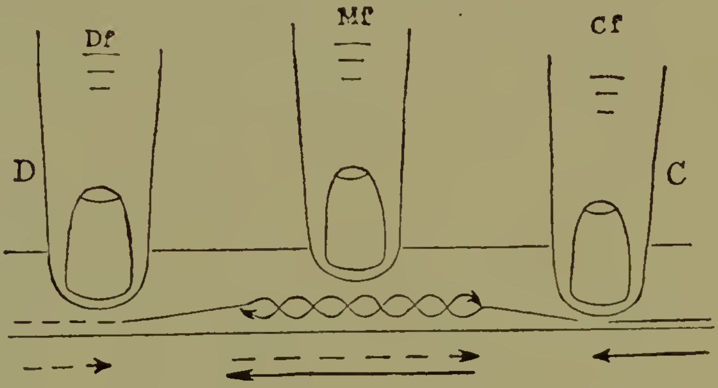


Diagram illustrating the theory of thrill by wave-interference. *Mf* would feel a thrill when the pressures made by *Cf* and *Df* respectively were so adjusted as to reduce both waves, and to render them equal.

As a fact, it is not necessary to use more than one finger. If by its means pressure be varied with nicety, a point may be reached at which the two opposed waves are so balanced as to give rise to a thrill.

It will be shown elsewhere that thrills are not limited to such pulses as possess an anastomotic wave, and the mechanism of thrills in general will receive consideration.

PART IV.

THE WAVE THEORY; AND THE INSTRUMENTAL STUDY OF THE PULSE WAVE.

INTRODUCTORY REMARKS ON THE INSTRUMENTAL STUDY OF THE PULSE.

HAD any technical study of the sphygmograph been ventured upon in these pages, they would have included a description of M. von Frey's elaborate tonograph, and of Professors Roy and Adam's sphygmometer [*]; but the reader must be referred to the original accounts. The sphygmograph leaves us in the dark concerning some of the most important elements of the pulse. Within certain limits, it registers variations of pressure (without, however, defining their absolute value); but unlike the finger, it does not even claim to judge of the volume of the artery at the various stages of the pulse wave, neither does it supply us with data as to any modifications in the rapidity of the blood stream. For a demonstration of the variations of the arterial volume and of the intra-arterial velocity we must turn to the plethysmograph and to the tachograph respectively.

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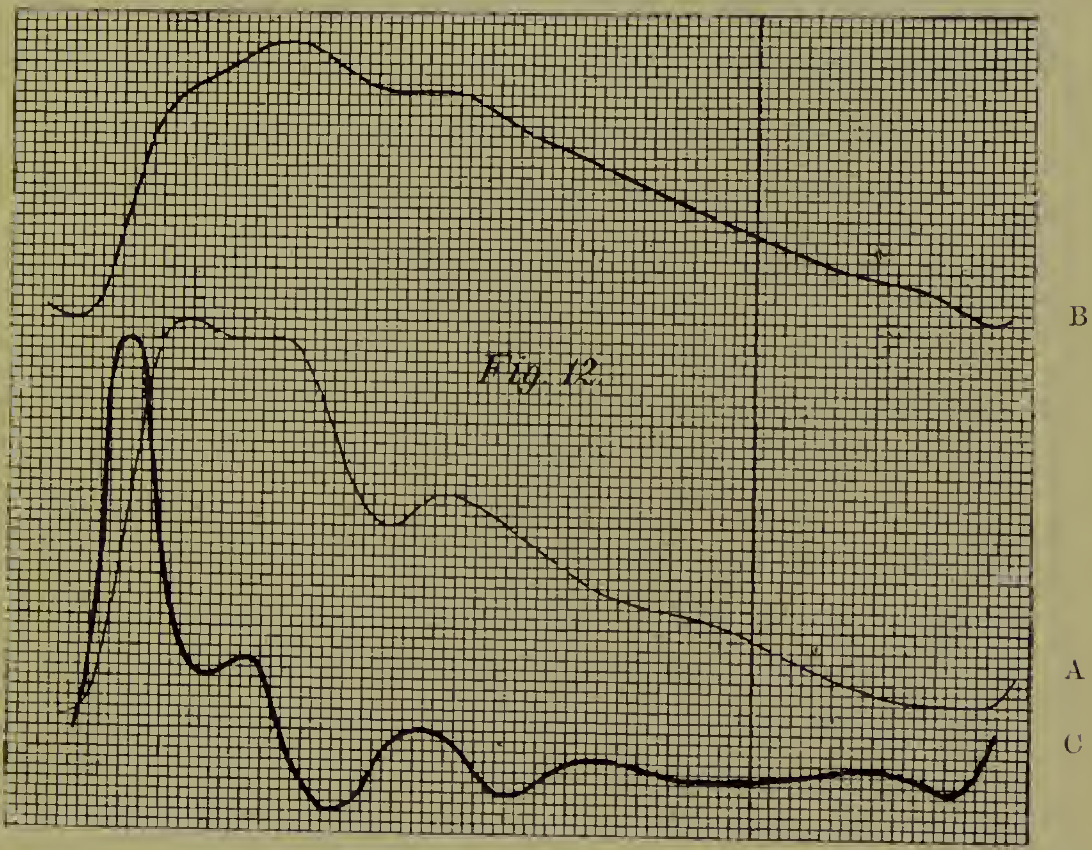
[*] *The Practitioner*, Feb. to July, 1890.

The need for a separate study of shape, volume, and velocity of the pulse is rendered obvious by the differences between the three curves, which may be termed respectively the sphygmogram, the plethysmogram, and the tachogram, obtained by means of the three instruments bearing corresponding names.

FIG. 89.



Pulse-pressure, volume, and velocity, expressed in lines (A. Fick). A: The sphygmogram (of the radial artery). B: The plethysmogram of the hand. C: The curve of velocity (in this case derived by calculation).

Other instruments have a less direct, though important, bearing upon the study of the pulse—viz., the cardiograph, but more especially the myo-cardiograph, and Dr. H. D. Rolleston's[*] instrument for the registration of intra-ventricular pressures. To these some allusion will be made in connection with the movements of the heart.

Lastly, reference should be made to Dr. George Oliver's pressure-gauge,[†] with which ingenious observations have been made on the variations of arterial pressure.

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[*] *The Practitioner*, vol. xliv. p. 162, 1890; also *Journal of Physiology*, vol. viii. p. 295, 1887.

[†] *The Practitioner*, February to August, 1893.

CHAPTER I.

ON THE PROPAGATION AND REFLECTION OF WAVES WITHIN ELASTIC TUBES FILLED WITH FLUID.

WAVE reflection enters largely into present theories of the pulse, and must claim some of our attention. The rebound of waves, as it occurs within elastic tubes, has been deeply studied by various observers.

The following brief review of the results of recent investigations are abstracted from von Kries' "Studien zur Pulselehre,"* and from M. von Frey's "Die Untersuchung des Pulses."† The latter work contains a bibliography of the subject, and may be regarded as the latest scientific treatise on the pulse. Among earlier works, that by Grashey, "Die Wellenbewegung elastischer Röhren und der Arterienpuls des Menschen sphygmographisch untersucht," deals, as the title indicates, with the physical aspect of the question: it is specially mentioned here, not only on account of its scientific importance, but because it supports a view to which reference must be made.

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* Freiburg in Breisgau, 1892.

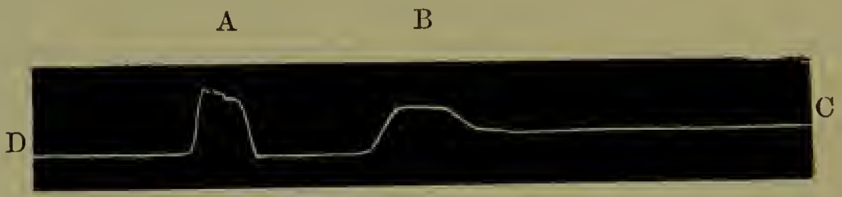
† Berlin, 1892.

The Total Reflection or Rebound of Waves.

The occurrence of wave-rebounds within elastic tubes has long been demonstrated in artificial schemata of the circulation. A question now arises, as to the condition of the wave after it has suffered reflection.

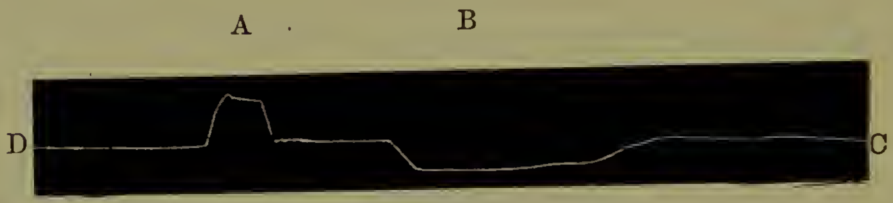
The original wave, which we will assume to be one of positive pressure, might rebound as a positive wave, as in Fig. 90, where *A* represents the primary, and *B* the secondary, or rebound wave; or it might conceivably, as in Fig. 91, be reflected as a negative wave.

FIG. 90.



A : Wave of positive pressure travelling towards D. B : Its rebound-wave, also positive (von Kries).

FIG. 91.



A : Wave of positive pressure. B : Its rebound as a negative wave (von Kries).

The event does not, however, depend on mere chance. The positive or negative character of the rebound is strictly determined by the circumstances of the experiment.

If the end of the tube be closed, any positive wave suffering total reflection at the spot will rebound as a positive wave, as in Fig. 90.

If, on the contrary, the extremity at which reflection occurs be open, the positive wave will pass into the negative phase, and rebound as a negative wave, as shown in Fig. 91.

The same rules would have applied, *mutatis mutandis*, had the primary wave been a negative wave.

The Partial Reflection of Waves in the Continuity of a Tube.

The reflected waves to which we have alluded are not exclusively produced by total reflection at the end of tubes. Similar reflections of a partial kind occur also in the length of tubes, whenever any sudden change occurs in their diameter or in the qualities of their walls, and whenever they undergo subdivision. A reservation must, however, be made in connection with the influence of the branching of tubes. Branching *may* occur without giving rise to any reflection; but, according to von Kries, this can only be the case when the dividing tubes alter their diameter in exact proportion to the alterations in the velocity of the wave. In other words, any increase in diameter must be compensated by a thickening of the wall, any decrease in diameter by a thinning of the wall. In the special case of a tube dividing into a number of small tubes of equal size, their aggregate diameter on the one hand and the velocity within them on the other, are the factors to be used in dealing with the problem.

Should the tube present at some spot a constriction, this would similarly be the seat of a positive rebound of limited extent; any widening of the lumen would on the contrary be the seat of a partial rebound of the negative kind.

The conditions thus far are simple, and the character of any of these rebounds might be predicted, given a knowledge of the tube.

Friction a Source of Partial Reflection of Waves.

In all tubes, however, but in some more than in others, the conditions are complicated by friction. Von Kries (*loc. cit.*, p. 24) has shown that friction (such as that occasioned by a short plug of loose cotton-wool inserted in the tube) determines a wave-rebound of the same variety as the primary wave.

Thus, a localised friction will produce a wave-rebound analogous (though on a smaller scale) to that induced by the sudden turning off of a stopcock.

It might happen that the tube traversed by a positive wave, whilst presenting a considerable dilatation, should, at the same spot, offer a considerable increase of frictional resistance. The positive rebound due to friction might, in a tube of this kind, exceed the negative rebound due to dilatation; and the returning wave might, in spite of the dilatation, remain a positive wave. Precisely this combination is found in the circulation, at the seat of the expansion of the arterial into the capillary lumen.

The *intrinsic* frictions occurring within the fluid itself, and between it and the tube walls, must of course modify the normal relations between flow and pressure. This influence von Kries has also verified experimentally. He has shown that, within narrow tubes, periodical oscillations of pressure, set up within the tube at one end, no longer keep strictly parallel with the oscillations of velocity.

Additional complications arise in tubes which contain a fluid in motion : the current itself may suffer acceleration or retardation in consequence of the passage of waves.

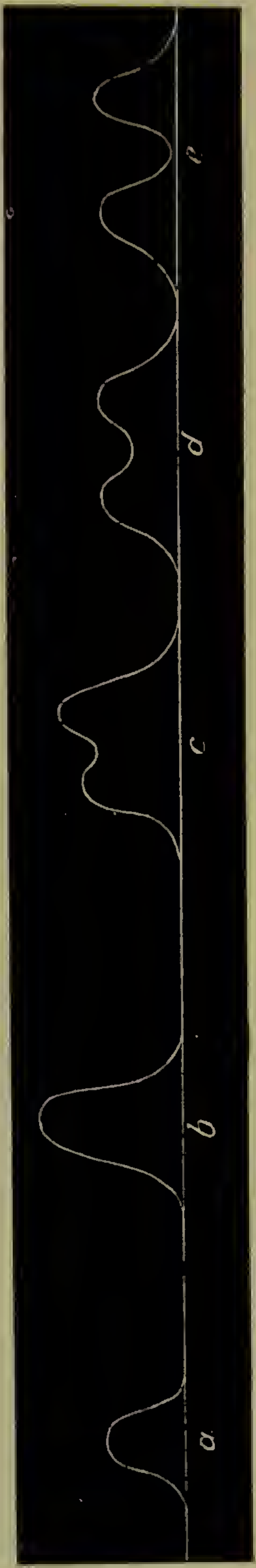
The Meeting of Waves.

When, at a given spot, two equal waves of the same kind meet from opposite directions, their pressures combine at this spot to a pressure twice as great as that of either. Their velocities, on the other hand, will exactly counterbalance each other. In the special case of the closed end of a tube, there being no possibility of any outflow, the rebound will be a positive one ; had the given spot been the open end of a tube, the positive wave of pressure would have been reflected as a negative wave.

Compound Waves.

Let us now consider the case of any other spot not a terminal one. Provided the distance from the end of the tube be greater than one entire wave length, the direct and the reflected wave will be recognisable as two distinct waves. Otherwise, the direct and the reflected wave will overlap, in proportions varying according to the distance between their summits, and they will give rise to various wave-combinations and shapes, to which it must here suffice to have called attention. Von Kries and Grashey have described these combined forms.

FIG. 92.



Various phases of the combination of a direct and of a reflected wave (von Kries).
a, *b*: Summation. *c*, *d*, *e*: Overlapping.

Wave Rebounds, Latent or Overlooked.

The diversity of the modifications as well as of the origin of wave-rebounds would naturally lead to their being sometimes overlooked and often misinterpreted. Thus, according to von Kries, Landois' "Ruckstoss Elevationen" and Moens' "Schliessungs wellen" are two ordinary instances of wave-rebound.

Landois' "Elasticitäts Elevationen" are explained by von Kries as oscillations such as may be imparted to a loop of indiarubber-tubing filled with water, by raising it at one end, and letting it fall again abruptly on to the table; or else as waves of elliptical deformation, such as may be set up within a suspended piece of elastic tubing filled with water by striking it a sharp blow with the handle of a scalpel. Neither of these conditions are fulfilled by the radial artery.

CHAPTER II.

ON THE VELOCITY OF WAVES.

I. PULSE PRESSURE AND VELOCITY. VON KRIES' TACHOGRAPH.

The Pressure-Wave and the Velocity-Wave.

ALL oscillations of pressure occurring within tubes filled with fluid are bound up with the production of current (or with the modification of any current that previously existed), in a direction from the point of the highest towards that of the lowest pressure.

If the fluid should previously be moving at a given rate, the descent of a wave of pressure down-stream will be marked at each point by a temporary increase in the velocity of flow. To this modification von Kries gives the name of *wave of velocity.* Although in this case running hand in hand, it is not identical, with the wave of pressure. For had the wave of positive pressure been travelling *up-stream,* the current would have suffered temporary retardation at each spot reached by the wave: in this case, the positive pressure-wave would have been accompanied by the negative velocity-wave—a combination leading to this result: *that the maximum of pressure at any point would coincide with the minimum of velocity.*[*]

Thus, let us repeat that, if the flow taking place within a tube be steadily in one direction, the passage of any waves of increased or diminished pressure will tell very differently according as the wave travels in the direction of the current or in a direction opposed to it; and for greater clearness in discussing these different combinations we shall use the convenient expression employed by von Kries, and speak of the transient acceleration or retardation arising in connection with the passage of a wave of positive or of negative pressure as a "wave of velocity." The wave of velocity travelling in the direction of the stream will be a "positive velocity-wave"—another name for a wave of acceleration; that travelling backwards will be a "negative wave of velocity," in other words, a wave of retardation.

On the Rate of Transmission of Pressure-Waves.

The rapidity with which the oscillations of pressure travel along the fluid is determined by the specific gravity of the fluid, by the thickness and elasticity of the membrane, and by the diameter of the tube. It is only indirectly dependent upon the pressure—viz., to the extent in which pressure affects the diameter and the dilatability of the tube. Animal membranes differ in a very important respect from other elastic membranes: the greater their tension, so much the less their capacity for expanding. It results that, with rising pressures, they will transmit waves at a quicker instead of a slower rate.

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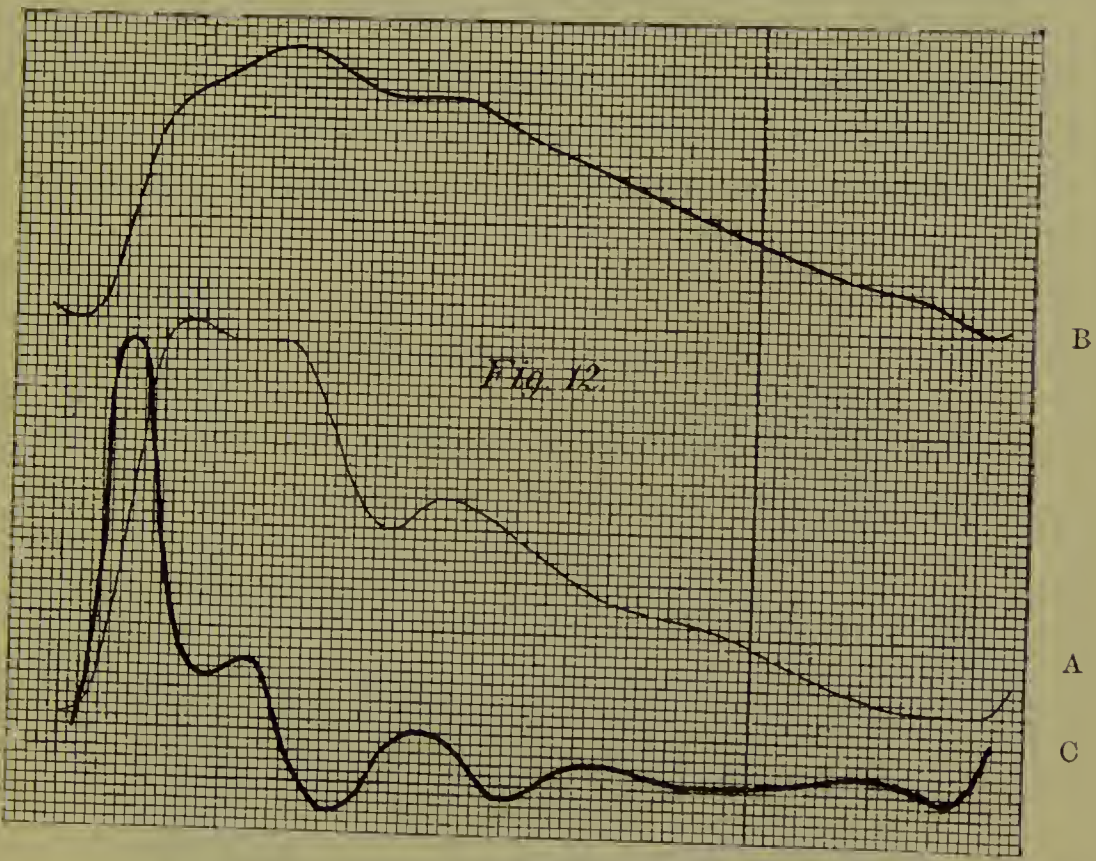
[*] Conversely, any velocity-wave must set up within the fluid a wave of pressure which will be positive or negative as the case may be.

Thanks to the close relationship shown to exist between waves of pressure and waves of velocity, it is possible to ascertain, from determinations made *at any one point* of the tube, the direction or directions followed by the waves within it (von Kries, *loc. cit.*, p. 13). This facility is of practical importance in connection with the circulation, since the arterial system presents conditions eminently favourable to the conversion of a centrifugal into a centripetal wave.

Method for Determining the Direction of Waves within Tubes.

The first idea of a graphic representation of the oscillations of velocity is due to Fick. The curve here reproduced from his original paper was not a direct tracing, but was derived by calculation from the plethysmographic curve or curve of volume; and in this case the plethysmogram was not taken from any one artery but from the whole hand. In the human subject a direct experimental determination of the volume of arteries is clearly impossible. The plethysmograph can only supply the pulse variations of a limb or of a part of a limb. On the other hand, it possesses the advantage over the sphygmograph that we can learn from it not only the relative but the absolute value of the variations. The pulse variations in the volume of any one artery may, however, under ordinary circumstances, be regarded as bearing a definite proportion to those of the limb.

FIG. 93.



A. Fick's simultaneous tracings of the left radial pulse (A), and of the volume-oscillations of the left hand (B); from which (C) the pulse-velocity was obtained.*

The curves were originally obtained by Fick by registering simultaneously the oscillations in the size of his left hand enclosed in a plethysmograph, and the pulsations of the left radial artery by means of the sphygmograph applied immediately above the latter. The oscillations of velocity (see Fig. 93), were derived by calculation from the oscillations of volume.

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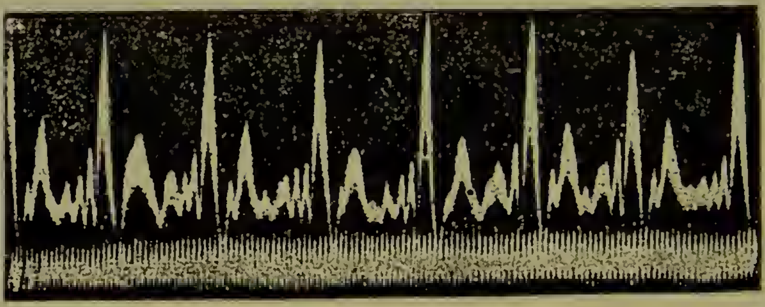
* *Verh. der Phys.-Med. Gesellschaft zu Würzburg*, 1886.

Since then, the tachograph invented by von Kries has rendered possible a direct determination of the velocity of waves, and we are therefore indebted to von Kries for a practical method of determining and graphically representing the direction of waves of pressure within the arterial system, based upon simultaneous records of the intra-arterial pressures and velocities.

Von Kries' Tachograph.

Von Kries' instrument registers on the bromide-paper of a revolving drum, enclosed in a dark case (which is provided with an appropriate slit), the oscillations imparted to the flame of a specially constructed lamp by the pulsatile changes in volume of the air-chamber (plethysmograph) in which the limb under observation is enclosed.

FIG. 94.

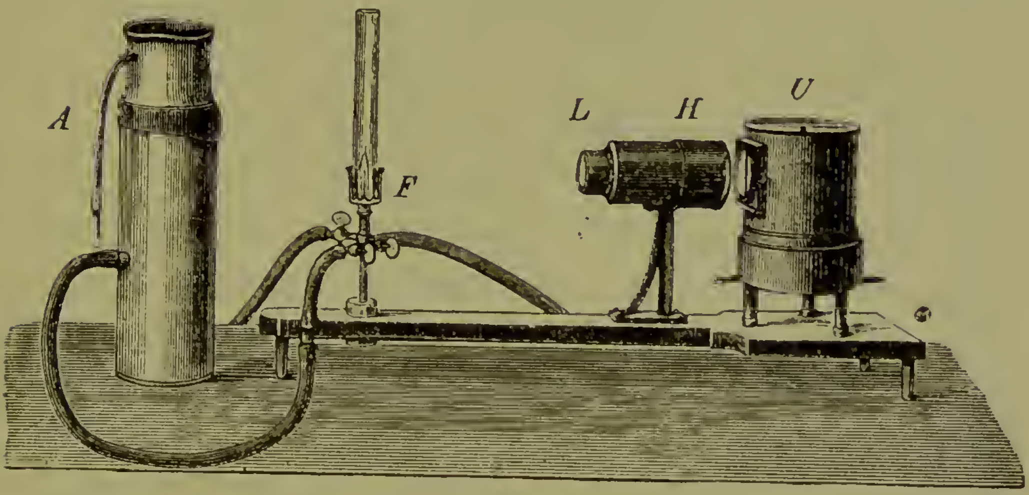


Tachogram taken by von Kries from the middle of the upper arm. (Reproduced from von Frey, *loc. cit.*, p. 168.)

At the side the image of another flame, influenced by the vibrations of a tuning fork, or of an organ-pipe, is projected by a mirror through the slit—and gives a time record to the tracing.

The tachogram here reproduced will convey a clear idea of the general characters of this form of pulse tracing. Von Kries draws special attention to the *very deep drop* which immediately follows the rise, and which coincides, in the *sphygmogram,* with a period of *high-pressure.* The dicrotic event is also a prominent feature in the tachogram of the pulse.

FIG. 95.



A: The air-chamber for the arm, connected with the gas flame F. U: The revolving drum, enclosed in a dark chamber provided with a slit. The oscillations of a time-recording flame (not shown) are also focussed on the drum. (Reproduced from von Frey.)

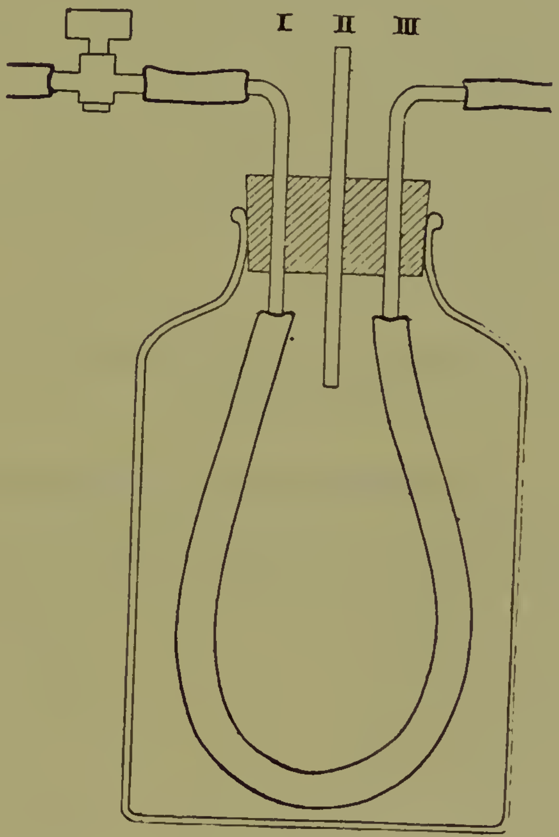
Instead of being, as in the plethysmographic process, immersed in water, the limb is surrounded with air only. A tube, which must be sufficiently broad to obviate any resistances, establishes a connection between this air space and the central air space of the gas flame, the oscillations of which are photographed on the moving surface, simultaneously with the time record.

Description of the Method.

The following principle underlies the method in question. Whenever, within elastic tubes, a wave travels down-stream, the maximum of pressure coincides at each point with the maximum of velocity; but should the wave be travelling up-stream, every local increase in pressure coincides with a local decrease in velocity. The accompanying schema (see Fig. 96), reproduced from von Frey's book, will afford a ready demonstration of these facts.

It is not at first obvious how the arrangement we have described can supply information as to the rapidity of the arterial current. This is best explained by von Frey's diagram, in which we deal with the variations in volume and in velocity of the contents of a single tube passing through an air space. Water is supposed to flow from a reservoir through the tube at a constant rate. A lever, placed (at I) on the tube before it reaches the bottle, indicates any variations in pressure, whilst the tachogram is obtained by connecting at II, the air contained in the bottle, with the sensitive flame of the tachograph. Air would obviously be driven out at II by any increase in the volume of the loop, and sucked in again by any decrease in volume, with corresponding results on the size of the flame, if connected. It is found that if a wave of positive pressure be sent down the loop in the direction of the stream, air is driven out, showing that the loop has increased in volume; in other words, more water flows in at I than flows out at III. Any increased rapidity of in-flow is in this way registered by a rise in the size of the flame. The exact opposite occurs when the wave of pressure is made to travel in the opposite direction from III to I. In this case, although the lever may register a rise in pressure equal to that previously recorded, the flame sinks instead of rising: in other words, the loop has lost volume, showing that the in-flow has become less than the out-flow.

FIG. 96.



Von Frey's schema: Water flows, from the tap, through the **U**-shaped elastic tube. The empty bottle freely communicates with the outer air at II. A recording lever is supposed to rest on the indiarubber connection at I.

In a rough schema of this sort the rate of out-flow is not absolutely uniform; but in the living subject since the venous out-flow is rendered nearly constant, the variations in velocity may be mainly ascribed to circumstances affecting the in-flow. Von Frey also shows that, if the loop were to be constricted at its middle, greater uniformity of in-flow would be secured, and the conditions found in the living artery would be more closely approached. A great portion of the pressure wave travelling down the loop would then suffer reflection at the constriction, and on its return to I would occasion a secondary rise of the lever; whilst the rapidity of in-flow would have varied from a maximum to a minimum, the maximum coinciding with the first of the two rises of the lever, the minimum with the second rise.

II. ON THE RATE OF TRANSMISSION OF THE PULSE-WAVE.

The Influence of the Elasticity of the Arterial Wall.

Were arteries rigid, the transmission of the systolic shock would be almost immediate, from the heart to the periphery—somewhat in the same way as the last of a continuous row of billiard balls is instantly displaced by the stroke dealt at the first. Since, however, arteries are elastic, the pulse-wave at the periphery can never be synchronous with that at the heart. The maximum rapidity of its transmission will be reached (for any given degree of elasticity), when, even during beats, the aorta and arteries are kept not only full, but under tension.

The great varieties found between arteries as regards fulness and tension will correspond to similar varieties in the rate of transmission* of the wave. With equal arterial fulness, and systoles equal both in volume and energy, the wave will travel quickest in stiffened arteries. Czermak,[*] Grunmach,[†] A. T. Keyt,[‡] and J. G. Edgren[§] all report analogous results as to the increasing rapidity of pulse transmission with age. Grunmach and Edgren also point to the same influence as arising from chronic nephritis with hypertrophy. The differences resulting from valvular defects are, according to Edgren, slight in comparison. On the contrary, the pulse-wave moves with least rapidity in those arteries which are most elastic. This leads us to inquire into the coefficient of elasticity[||] of arteries.

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* In this connection see the remarks on the pulse of aortic reflux.

Professor Roy's experiments[¶] on the elasticity of the arterial membrane have furnished some important results.

Transverse strips of aorta, 1 cm. wide, were lengthened by a load of 100 grammes in the following proportions:

50	p.c. in the case of	a child *æt.* 2½
43·3	,,	a man *æt.* 22
48·2	,,	a man *æt.* 26
16·6	,,	a man *æt.* 71[**]
22·0	,,	a man *æt.* 76[**]

Roy's results also point to an enormous elastic capacity of the pulmonary artery.

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[*] Gesam. Schriften, Leipzig, 1879, bd. i. p. 708.

[†] Virchow's Archiv., bd. 102, 1885, s. 565.

[‡] "Sphygmography and Cardiography," New York and London, 1887.

[§] Nordisk. Med. Archiv., bd. xx., 1888; see also Skandinav. Archiv., bd. i., 1889, s. 67.

[||] By coefficient of elasticity (Elasticitätsmodul) is understood the increment of tension which would be needed to increase the diameter to double its length, were the increase to remain proportionate to the tension throughout.

[¶] *Journal of Physiology*, vol. viii. p. 25, 1881.

[**] These were cases of arterio-sclerosis, but the strips used were free from calcareous deposit.

Unfortunately, determinations of this sort are practicable only in the larger arteries. It must remain matter for conjecture how and to what extent elasticity may vary in the different sections of the great bulk of the arterial system. Instead of being able to use this as a known quantity for the calculation of the velocity of the wave, we need to determine the latter experimentally in order to gain some idea of the tension of the walls of small arteries.

Various Estimates of the Velocity of the Pulse-Wave.

Von Frey states that E. H. Weber found, between the pulses of the external maxillary and of the anterior tibial arteries, an interval of one-sixth or one-seventh of a second; he estimated from this the velocity of a pulse-wave as ranging between 7·92 and 9·24 metres per second. This wide range is exceeded in other estimates. Czermak found a rate of 6·70 metres per second for the upper, and of 11·16 metres for the lower extremity. Most observers agree with him in adopting a quicker rate for the latter; but both Keyt and Edgren find the velocity in the upper limb a higher one, in the following proportions: 7·37 to 6·83 (Keyt); 7·32 and 7·63 to 6 20 and 6·59 (Edgren).

The Influence of Calibre, Blood-Pressure, and Arterial Tone on the Velocity of the Pulse-Wave.

Although the aggregate sectional area of arterial subdivisions increases with their distance from the heart, and the size of the wave therefore decreases, the velocity of the latter need not decrease, provided there be a proportionate variation in the tension. Von Frey aptly suggests, that the rapidity of the peripheral rebound-wave, which does come under our observation, favours the view that small arteries possess very good capacity for the rapid transmission of waves.*

Moens (quoted by von Frey, *loc. cit.*, p. 132) studied the velocity of the pulse-wave during the performance of Valsalva's experiment (straining with filled chest). During quiet breathing, the velocity was 8·4 metres per second ; during strain it fell to 7·0 metres. In animals he found an analogous diminution during stimulation of the vagus. For this retardation he seeks an explanation in the diminished ventricular fulness, and in the fall in arterial pressure (which is coupled with a corresponding increase in the amplitude of the pulse oscillations).†

Moens suggests, on the strength of his observations, that the amount of the arterial blood-pressure might be ascertained from determinations of the velocity of the pulse-wave—a very unreliable mode of measurement, since, as von Frey shows, arterial tone is apt to vary from one section of an artery to another.

Von Frey (*loc. cit.*, p. 137) draws attention to the retardation (14 p.c.) of the radial pulse obtained by Grunmach by keeping the arm in a warm bath—or by placing a light elastic band on the fore-arm. Assuming the general blood-pressure to have remained the same, it is made probable by this experiment that the rapidity of transmission is locally depressed by a locally lowered arterial tone. It should be borne in mind that arteries in contracting alter, not only their coefficient of elasticity, but also their thickness.

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* It should be remembered that, whereas the aortic blood is comparatively at rest during the heart's diastole, the arterial blood at the periphery is steadily flowing. This circumstance must exert some influence on the rate of transmission of waves.

† Roy and Adami's experiments, as well as von Frey's, show a rise in the basal line of the sphygmogram.

CHAPTER III.

THE REBOUND OF ARTERIAL WAVES OF BLOOD-PRESSURE.

I. Von Kries' Method applied to the Circulation.

Reverting now to the circulation, we perceive how a comparison of simultaneous tachograms and sphygmograms would enable us to ascertain the direction followed by a wave of pressure. In this way von Kries has arrived at definite conclusions concerning the meaning of the sphymographic events. These conclusions, which are largely supported by von Frey, will be dealt with in due place.

The occurrence within the arterial system of rebounds of the primary or systolic ventricular wave, long regarded as probable, no longer admits of doubt; but to what extent the laws which govern the behaviour of waves within elastic tubes may apply to the circulation is a question not easily answered. The most recent observers, von Kries, von Frey, and Krehl, have satisfied themselves that the same laws are applicable. We propose briefly to set forth some of the evidences and the views expressed by von Kries on the characters and most likely modes of production of arterial rebound-waves.

On the Sites of Reflection of Intra-Arterial Waves.

I. Waves set up within an artery rebound, not only from the points of division of the vessel, but from any other point where the muscular tone is locally different from the rest.

In any elastic tube, a local alteration of the coefficient of elasticity will lead to the reflection of a wave. Since, however, the blood is constantly flowing, a wave-rebound must also take place at the seat of each arterial division. We may assume that a healthy artery usually possesses an even calibre in the intervals between its branchings. Nevertheless (putting aside the pathological changes which might modify the lumen), it is consistent to imagine that the muscular coat may be the seat of local contractions or relaxations, and that a narrowing or a dilatation affecting all the arteries of a given district may occasion a rebound perhaps hardly noticeable in the individual vessels, but perceptible in the larger vessels, into which the several rebound waves converge and are piled up.

II. The *chief* site of the rebound of intra-arterial pressure-waves is the periphery of the vascular system—the capillary area. Owing to their very small diameter, capillaries present, relatively to their capacity, a vast surface of friction which presumably more than outweighs the great increase in their aggregate lumen. As pointed out by von Frey, intra-capillary resistance is enormously increased by the blood corpuscles, which cannot but add much to the lateral friction of the blood-stream, whilst their tendency to obstruct the smallest capillaries sets up a yet more efficient obstacle to the passage of the wave, and under ordinary circumstances determines its almost total reflection.

The Character and Direction of the Reflected Arterial Waves.

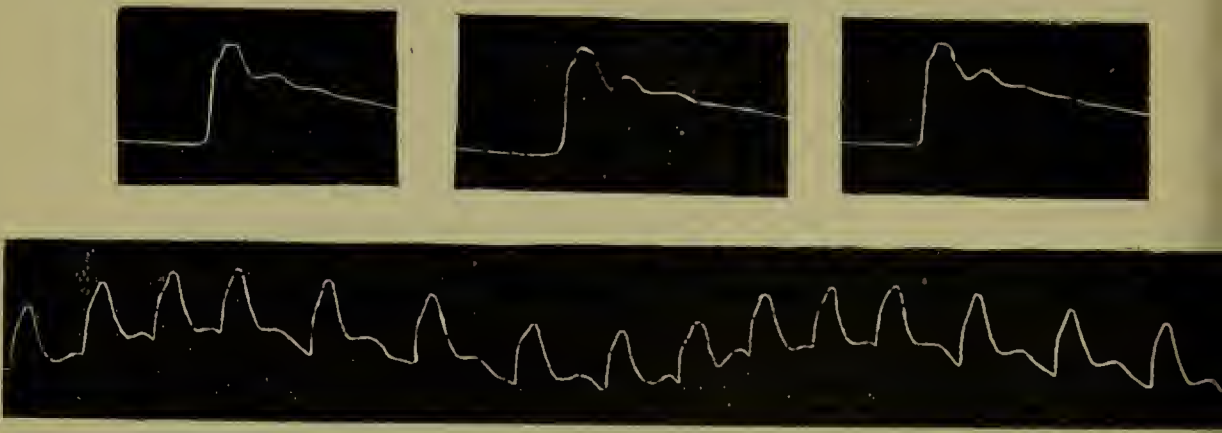
Von Kries arrives at the conclusion that, at every branching of the artery, some kind of rebound of pressure must take place. The ideal adjustment which alone might prevent a local rebound is supposed by him to be hardly ever, if ever, met with. Concerning the nature of this rebound, opinions have differed. Grashey, whilst admitting that the rebound of a wave of pressure (whether positive or negative), could take place without change of signs—*i.e.*, without the wave being thrown into the opposite phase—contends that this can only be the case either when the vascular lumen is diminished, or when the vascular wall becomes less extensile : and that, under all other circumstances, positive waves of pressure would be reflected as negative ones, and *vice versa*. In opposition to this view, von Kries, and subsequently von Frey, have satisfied themselves that, partly owing to increased friction (von Kries), partly owing to the resistance of the blood corpuscles, the widening of the capillary area does not cause the wave to be reversed, but that the rebound from the capillaries remains a positive rebound. The positive character of the rebound may be regarded as proved by some of the tactile observations recorded in Part III.

The Proofs of a Peripheral Reflection of Arterial Waves.

Proofs of a peripheral rebound of the pulse-wave have been sought in two directions : (1) by physiological experiments ; (2) by a comparative analysis of pulse-tracings taken at various distances from the heart.

(1) The experimental demonstration which we owe to von Kries* and von Frey, consisted in determining the arterial pressures in animals bled to death, in whom an artificial circulation of defibrinated blood was kept up by means of intra-aortic injections. In this way von Kries succeeded in obtaining evidence of a secondary wave in the femoral artery of dogs (the normal femoral tracing having previously been taken during life).

Fig. 97.



The continuous tracing of the femoral pulse was taken during life; the artificial pulse-waves are also from the femoral artery (von Kries).

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* Von Kries, *loc. cit.*, p. 62, 63.

Under the circumstances of the experiment, this wave would have had its origin neither in the aorta itself, nor in the spring manometer employed.

Hoorweg's failure to obtain analogous waves is attributed by von Kries to the great length of india-rubber tubing (10 metres) inserted between the source of pressure and the aorta. The same faulty arrangement was adopted by Bernstein, who used 7 metres of tubing, and also failed to obtain any result. In the hands of von Frey and Krehl, the experiment was entirely successful.

Evidence of reflection might also be obtained by comparing the differences in the intervals between successive waves at the periphery and nearer the heart; this method would be more promising but for the fact that, after travelling a long distance, waves lose their definition and undergo deformation, especially in channels exposing them to much friction.

It is pointed out by von Frey,* that an excellent proof of the positive reflection of arterial waves has been unintentionally supplied in the course of Hürthle's investigations.

The proof is an indirect one. The oscillations of pressure observed in the femoral artery were found by Hürthle to be considerably greater than those in the carotid of the same animals. Thus, from 78 to 220 mm. of mercury was the range for the femoral; from 74 to 168 mm. only for the carotid: in another experiment in the femoral, the pressure ranged from 94 to 249 mm. of mercury, whilst in the carotid it did not exceed from 94 to 183 mm.

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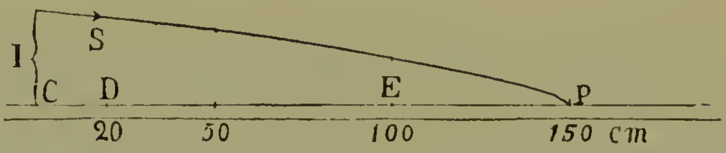
* *Loc. cit.*, p. 33.

This unexpected result can hardly find a better explanation than in the action of peripheral reflection, leading in the more distant vessel to the summation of direct and of reflected waves.

II. VON FREY'S DEMONSTRATION OF THE THEORY OF ARTERIAL REBOUNDS.

The following abstract from von Frey's book,* in conjunction with his diagrams, will throw further light on the difficulties connected with a study of the pulse-wave, and on some of the explanations supplied by the theory of wave-rebound.

FIG. 98.



The head of the systolic wave (S) has reached P, after lapse of 0·15 sec.; its summit has not yet entered C.

The Diagram.

For greater simplicity, the aorta and the arterial system are represented by a single elastic tube 150 cm. in length, of even diameter throughout, open at the cardiac end *C*, and closed at the peripheral end *P*. This is supposed to contain a fluid at rest, traversed by a wave which possesses a uniform velocity of 10 metres per second, and which is free from the disturbing influence of friction.

The horizontal line *CP* represents the tube; and the upper line, the successive levels attained by the pressures within it.

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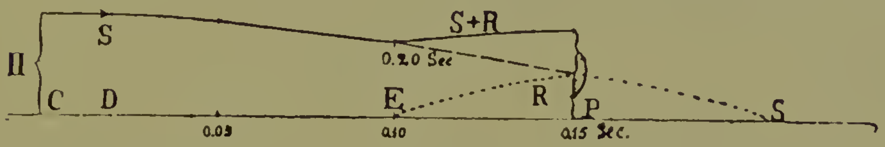
* *Loc. cit.*, pp. 181–192.

The Pulse-Wave and its Reflection.

A. The Primary Rebound.

The positive (aortic) wave is supposed to occupy 0·2 seconds in reaching its full development from its beginning to its acme. Starting at *C*, it will only need 0·15 seconds to arrive at *P*, where it must be reflected—as shown diagrammatically in II; and by the time its summit has entered the tube (viz., after 0·2 sec.), its beginning will have travelled back as far as *E*, as a positive refluent wave; and, therefore, the pressure at each spot between *P* and *E* will be raised by a corresponding amount. This is expressed in the diagram by superposing the reflected portion over the earlier portions of the wave.

FIG. 99.



At the end of 0·2 sec. the summit of the wave has entered C. Its head would have reached S′, but is reflected as R E. R E being superposed, as so much additional pressure, to the original wave, the local distribution of pressure, at that moment, is represented by the line S S + R. A minimal pressure occurs at E; the two maxima at C and at P.

The diagrams III and IV are constructed on the same principle, and represent the conditions after lapse of 0·25 sec. and 0·30 sec. respectively.

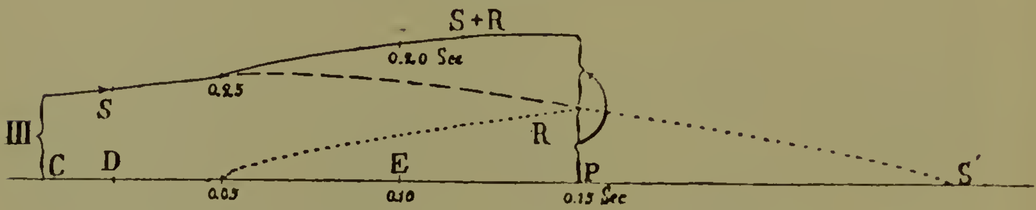
The Changes in Pressure.

Let us consider the successive pressures at a point *E*, distant 100 cm. from *C*. The wave will not reach that spot until 0·10 sec. have elapsed since the aortic valves have opened a way for it into the arterial system. The following figures represent the increments of pressure at successive intervals of time :

TIME.	PRESSURE.	
0·00 sec.	0·0	pressures due to primary wave
0·05	0·0	
0·10	0·0	
0·15	1·7	
0·20	3·6	

After lapse of 0·25 . . . . 5·0 would be the pressure due to the primary wave only.

FIG. 100.



S S′: The length of wave after 0·25 sec. S S + R: The local distribution of pressure at that moment, P S′ having suffered reflection at P.

But meanwhile (as shown in diagram III) an additional pressure of 1·7 has accrued at point *E* from the passage of the reflected part of the wave—and the total pressure at *E* amounts to 6·7.

After lapse of 0·30 sec. the pressure at *E* is higher still (Diagram IV).

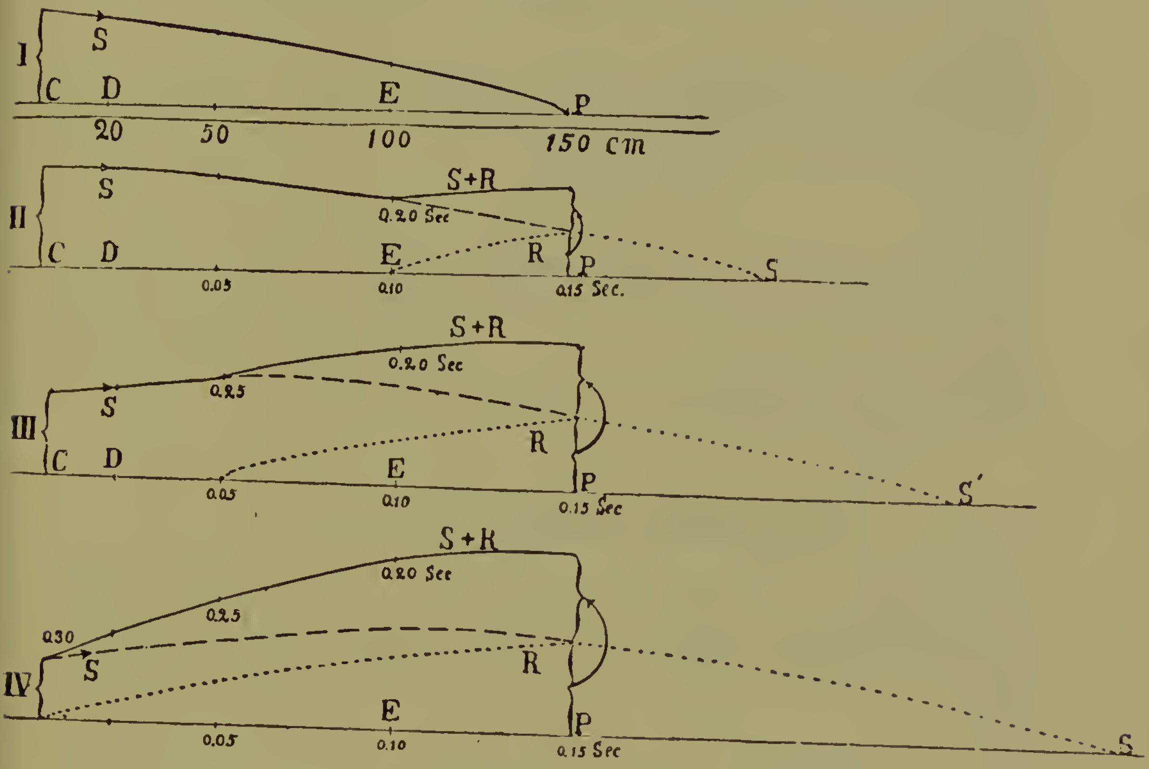
Bearing of these Data on the Arterial Pulse.

An important fact is illustrated by this mode of demonstration. The highest pressure at *E* will not always coincide with the moment of transit of the apex of the primary wave. Whenever the reflected wave rises more quickly than the primary wave falls, the summit of the combined pressures will be later : the apex of the pressure-curve will be broadened. And again, the nearer to *P* is the point selected, so much the smaller will be the inequality between the primary wave-pressure and that of the superposed wave, until at *P* the pressure of the primary wave is exactly doubled.

The Femoral artery of man presents a characteristic broadening of the summit, which is due to the combination of a primary and of *a reflected wave, whilst in the less distant Radial artery the summit of the primary and that of the reflected wave are less far apart.*[*]

In animals, direct measurements show that the femoral pulse is often a bigger one than that of the carotid, presumably because, in the former, summation of the pressures more readily occurs.

FIG. 101.



Von Frey's diagram † (slightly altered) of the course of a systolic wave, in an elastic tube (or artery) 150 c.m. in length.

On the other hand, the tachograph shows, in the arteries of the limbs, a rapid fall of the primary summit towards the periphery. It is noteworthy that a similar diminution takes place in the ensuing minimum of velocity.

Had the pressure been determined at the point *D* (20 cm. distant from *C*), the record would have been as follows :

TIME.	PRESSURE.
0·00 sec.	0
0·05	1·0
0·10	2·9
0·15	4·5
0·20	5·6

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[*] See Figs. 102*a* and 102*b*, p. 214.

† *Loc. cit.*, p. 182.

The apex of the primary wave occurs 0·02 sec. later, and the pressure begins to fall again. But this fall only lasts 0·03 sec., after which begins a fresh rise to a yet higher maximum. The fall of the primary wave and the subsequent rise, due to the advent of the rebound wave, are shown in Diagram II; and it will be readily understood that the intervening minimum will have a greater depth the nearer to the heart is the point selected.

The two summits might likewise be separated by diminishing the velocity or the length of the waves.

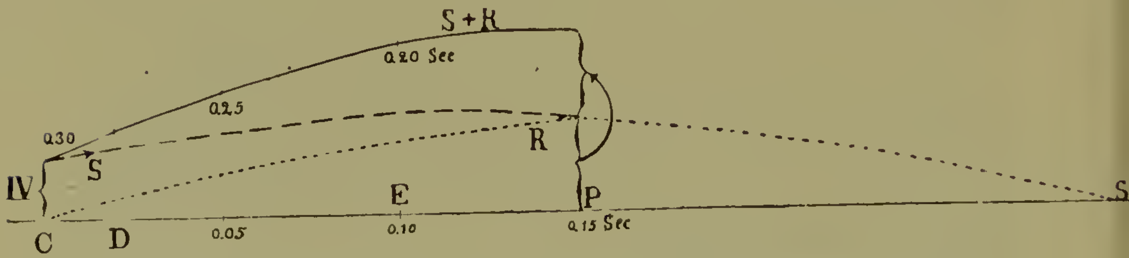
Instances of this kind are also to be found in the living subject.

It must be borne in mind, however, that in the living artery the reflected wave is so much reduced by friction, etc., that it will hardly raise the pressure above that of the primary wave, except in the neighbourhood of the summit of the latter.

B. The Secondary Rebounds.

Reverting once more to the diagram, we will now assume that the wave reflected towards *C* finds that opening closed. The wave would suffer a second reflection at *C*; and would resume the direction of the original wave. Von Frey proposes to distinguish it from the latter as a wave *of the second order*. Its relations to the reflected wave will be precisely analogous to the relations described above as existing between the primary and the reflected

FIG. 102.



The starting point C reached again, after 0·30 sec., by the head of the rebound wave. Henceforth a secondary reflection must occur at C (if closed); and yet later, a tertiary reflection at P.

wave. Therefore, simultaneous observations at symmetrical points in the vicinity of C and in the vicinity of P respectively, would give the following results:

In the vicinity of C: (*a*) a first summit, that of the primary centrifugal wave;

(*b*) a second summit, the joint product of the reflected wave *of the first order*, and of the centrifugal wave *of the second order;*

(*c*) a third summit belonging to the combination of the centripetal wave *of the second order*, and of the centrifugal wave *of the third order*, etc.;

And in the vicinity of P: (*a*) a first summit due to combined direct and reflected waves *of the first order;*

(*b*) a second summit, compounded of the direct and reflected waves *of the second order*, etc.

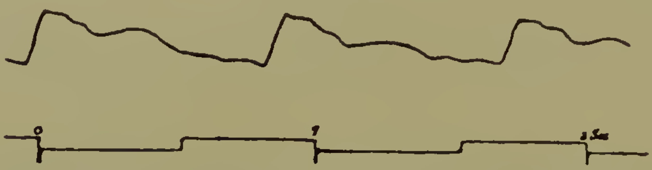
Thus the maxima at the two ends are both composite, but not analogous; the central maxima resulting from waves of different orders—the peripheral maxima, of waves of the same order.

As a practical deduction from the above, the summits of the pulse-waves of two arteries at points equidistant from the heart may be compared; not so those of two arteries unevenly distant from the heart. In particular, the *dicrotic* elevations of the arteries of the limbs are regarded by von Frey as representing the summation of the direct and reflected waves *of the second order.* The alternation which he has frequently observed between the secondary elevations of the innominate, and those of the external iliac pulse, leads him to suspect that those of the innominate belong to the central type (combination of a direct wave *of the n^{th} order*, and of a reflected wave *of the* $(n+1)$ *order*).

The Rebounds in the Living Arterial System.

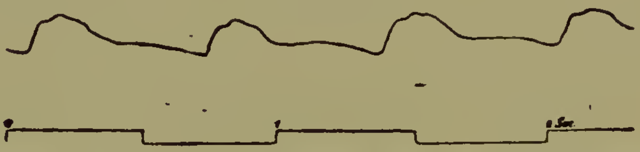
Passing now from the crude simplicity of the diagram to a consideration of the real conditions of the arterial and capillary system, we must account for an enormous number of small rebounds which by mutual summation will ultimately (in the aorta), grow to a considerable total. Owing to their multiple diversity in time, their resultant wave will lose much of its height and become broader. The undoubted occurrence of resultants of this kind suggests their probable origin from large vascular areas such as those of the intestine, of other viscera, and of the limbs:

FIG. 102*a*.



Brachial tracing, with time-record, by von Kries, reproduced from von Frey, *loc. cit.*, p. 168.

FIG. 102*b*.



Femoral tracing from the same subject, very different in shape from the brachial tracing; illustrating the dependence of any pulse-curve upon the kind and arrangement of its component rebounds.

it also suggests the possibility that the existing inequalities in distance from the heart may be partly compensated by corresponding differences in the velocities, as a result of differences in the condition of the arterial walls in different regions of the organism.

The alterations due to muscular contractility under nerve influence, open up an almost incalculable range of possible combinations.

Von Frey's numerous observations on the pulse of the innominate artery have yielded most variable results in different animals, some of the pressure-curves being monocrotic, others provided with three or with four summits. Even in the same animal the tracing will entirely alter its character in the course of a single experiment. The pulse will pass from a monocrotic into a polycrotic phase, becoming either anacrotic * or katacrotic, without the occurrence of any alteration either in blood-pressure or in cardiac rhythm. The only explanation for this variability is to be found in vasomotor influences.

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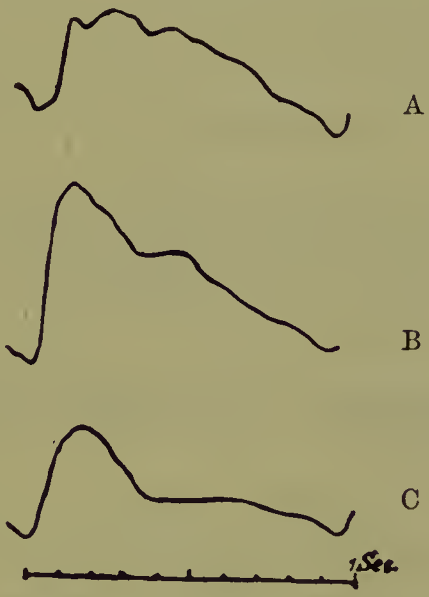
* If a rebound-wave should coincide with the ascent of a direct one, an anacrotic tracing will result (von Frey, *loc. cit.*, p. 173).

FIG. 103.



Tracings of the Temporal (A), of the Radial (B), and of the Dorsalis pedis pulse, taken in rapid succession in the same person (von Frey[*]): Illustrating the essential diversity in their configuration.

Von Frey also draws attention to the short-circuit rebounds taking place from one branch of an arterial bifurcation into the other[†]; and lastly, to the reflux waves due to anastomosis.

In conclusion, the thorough discussion of any pulse-tracing is, strictly speaking, impossible in the absence of a knowledge of the number, origin, and direction of the waves which share in its production.

The centripetal waves of distant peripheral parts, can be traced to a definite mode of production; but the centrifugal waves may have their origin, not only in the heart, but in any other part of the body capable of generating an arterial rebound, and of transmitting it to the arteries under observation.

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[*] *Loc. cit.*, p. 161.

[†] Reference to these local rebounds, described by von Kries, will be found at page 257.

CHAPTER IV.

THE PULSE-WAVE STUDIED IN THE PULSE-TRACING.

The Sphygmograph: Its Aims and Its Limits.

Leaving aside the gross imperfections of some of the special forms, the shortcomings of the sphygmograph in general have hitherto been of three kinds. It has failed to report as to the hardness or other tactile qualities of the pulse—to gauge the absolute value of blood-pressure—and to supply trustworthy information as to the size of the pulse, and the direction of its waves. Some of these data are furnished by the plethysmograph and the tachograph.

The qualities of a good sphygmograph are briefly described by Roy and Adami:

> To obtain satisfactory graphic records of the pulse, an instrument is required which will give with certainty similar results when applied at different times, when the pulse has not undergone alterations in the intervals; which, secondly, can be applied without difficulty; thirdly, the pressure upon the artery must be capable of being regulated with exactitude; fourthly, it must give tracings sufficiently large to enable us to distinguish minute variations in the characters of the pulse-wave; fifthly, the curves obtained must be free from inertia-vibrations; sixthly, it must be

capable of measuring the blood-pressure within the artery; and lastly, it must be such that it can be conveniently employed at the bedside.

Roy and Adami claim for their instrument, the sphygmometer, described and depicted in the *Practitioner* (vol. xlv., p. 29, 1890), that it fulfils most of these conditions.

The Sphygmogram.

All observers are agreed as to the main features of the sphygmogram. These consist (in Roy and Adami's nomenclature) of:

(1) A *primary wave;* and of at least three secondary waves;

(2) The upstroke of the primary wave is continued into *the first secondary wave;*

The downstroke presents various events:

(3) A predicrotic wave, or *second secondary wave;*

(4) *A dicrotic notch;*

(5) A "post-dicrotic"[*] wave, or *third secondary wave;*

(6) A *rounded shoulder* included between the post-dicrotic wave and the base line;

(7) "Finally, in tracings taken near the heart, a small *notch* and short *positive wave* corresponding in time with the commencement of the ventricular systole."

In addition to these manifest constituents, other elements, which are partly latent, are held by some to take an important share in shaping the sphygmogram.

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[*] "Post-dicrotic" is used instead of "dicrotic." Both names mean the same event, viz., the wave immediately following the notch.

Its Interpretations.

Considerable difference of opinion prevails as to the origin of the leading features of the pulse-tracing, and as to their individual variations. Von Kries and von Frey attribute much to peripheral influences and wave rebound. Roy and Adami, on the other hand, lay great stress upon the mode of the cardiac contraction as influencing the configuration of the curve.

The two views might almost be contrasted as the *central* and the *peripheral interpretation* of the sphygmogram: Roy and Adami recognising, in addition to the *waves* of *inertia*, among which they include the dicrotic wave, *three heart-waves* (a primary wave due to the contraction of the heart-wall—a first secondary or "papillary wave" due to the late and brief contraction of the papillary muscles—and a second secondary or "outflow-remainder" wave, due to the continued contraction of the heart-wall, outlasting the papillary contraction); whilst von Kries and von Frey are content with a *single heart-wave*, the peripheral rebounds of which are supposed to be such as to give rise to the various accidents in the outline.

A.

ROY AND ADAMI'S VIEWS.

The Mode of Production of the Several Events.

Roy and Adami's important experimental observations on the function of the papillary muscles lead them to suggest alterations in the interpretation of the pulse-trace, and in the names to be applied to its several constituents.

(1) For the term "percussion-wave" they substitute that of "papillary-wave," on the ground that the portion of the pulse-curve which corresponds in time with the ventricular outflow agrees in form with the intra-ventricular pressure-curve.

(2) The rounded shoulder or secondary wave, hitherto known as the "tidal or pre-dicrotic," should be called the "outflow remainder-wave." It coincides in time with the third phase of ventricular systole, that which precedes the dicrotic notch.

(3) The dicrotic notch is regarded as a wave of inertia of the blood in the aorta and larger arteries, causing a negative wave at the root of the aorta. This is propagated in the same direction as the positive wave. It may be considered as the result of the cessation of the ventricular outflow.

The depth of the dicrotic notch is of course influenced by the height of the wave which follows it. The size of this post-dicrotic (dicrotic) wave is not determined by inertia alone. Roy and Adami have observed that this positive wave often coincides exactly with the onset of the ventricular diastole, and are inclined to connect it, at least in part, with the sudden change in the rigidity of the heart-wall at that moment, an influence which might be transmitted to the adjoining vessel. In cases in which this synchronism did not obtain, they have sometimes noticed two waves instead of one, and one of these did coincide with the onset of diastole.

A second, much smaller wave, which is also positive, follows the post-dicrotic wave. Roy and Adami regard it as due to inertia; at least, they are unable to find any other cause for it.

Lastly, in tracings from the early portion of the aorta, a small notch and a short positive wave immediately precede the upstroke. "They appear to be due to the pull upon the aorta which results from the first part of the ventricular systole."

The Time, Size, and Rapidity of the Upstroke.

At the root of the aorta the beginning of the pulse-wave does not bear a constant relation to the onset of the ventricular systole (a fact apt to influence the form of the pulse-wave). For there may be delay in the opening of the sigmoids—due to intra-aortic pressure—or again, the intra-ventricular pressure may be raised more or less quickly during the earlier part of the systole.

The *height* of the systolic rise is influenced :

(1) by the volume of ventricular output ;

(2) by the freedom of outflow into capillaries ;

(3) by the degree of arterial wall rigidity ;

(4) by the degree of pressure of the recording instrument on the vessel.

Its *rapidity* varies with the rapidity of the outflow from the heart.

The point corresponding to the cessation of ventricular outflow, may be determined by the simultaneous use of the myocardiograph. The cessation of the shortening of the muscles will indicate this point, which must occur in the tracing above the dicrotic notch. Usually (the cessation being gradual) no indication is traceable in the pulse-curve.

The Sphygmographic Characters of the Pulse of High Tension as seen in the Downstroke.

Roy and Adami have conclusively shown that the mere shape of the pulse-curve often conveys no information as to the height of the blood-pressure, and that it is necessary to state the amount of the extra-vascular pressure employed. Considerable oscillations of the lever are observed in some cases of high tension. The pre-dicrotic wave in them may be as short in duration as it is in pulses of low tension.*

The Sphygmogram not an Obvious Record of the Medium Arterial Pressure.

It is pointed out that much confusion would arise, if the mere form of the pulse-wave were regarded as a safe guide to the height of the medium arterial pressure.

By comparing a healthy sphygmogram with one obtained from a patient on the eighth day of erysipelas, the authors arrive at the conclusion that

> "The medium arterial pressure may be reduced considerably below the normal without any change in the form of the pulse-tracing being necessarily produced thereby."

Again, the pulse-curves in cases of Anæmia

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* The converse to this has, however, not (as far as known to the author) been alleged. A prolonged pre-dicrotic wave coinciding with large size of the main wave has not been observed in cases of low tension. We may regard Mahomed's test as a safe indication of the existence of tension in the large group of cases in which high tension is of the *sustained* kind. His test should be regarded as trustworthy where it applies as a positive test, but it cannot be used, as at one time alleged, as a negative test, since high tension may exist in its absence.

Mahomed's test is the following :—

A line is drawn from the apex of the tracing to the bottom of the dicrotic notch. If any part of the pulse trace rises above this connecting line, high pressure is shown to exist (Guy's Hosp. Rep., 1879, *p.* 371). *It is also stated that the level at which the dicrotic event occurs is an indication of the amount of pressure; the higher position meaning the higher pressure.*

(Hydræmia) may fail to indicate the existence of very different types of pressure. Thus :

> "A patient (from whom Fig 30 * was taken) was intensely anæmic, and had functional mitral incompetence. Nevertheless, the arterial pressure was not low, the minimum being 85 mm. of mercury. As the dicrotic depression was very marked and deep, analogous to that seen in the so-called low tension pulse, therefore a typically dicrotic pulse-wave, of the kind usually called the low-tension pulse curve, may be present in cases where the blood-pressure in the systemic arteries is little, if at all, below the normal."

In another patient the minimum pressure was lower than normal; nevertheless the pulse curve did not resemble the so-called low-tension pulse.

B.

VON FREY'S VIEWS.

Von Frey, like von Kries, has little to say concerning the mode of the cardiac contraction as directly influencing the fluctuations of the outline of the pulse-wave.

The differences between his analysis of the sphygmogram and that given by von Kries are not considerable, and, but for the few remarks which follow, the accounts given by the two authors might be conveniently blended.

The Influence of the Attendant Circumstances on the Pulse Curve.

Mistakes in interpretation are often traceable to the following influences :

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* *Loc. cit.*, vol. xlv. p. 22.

(1) Pulsatile, so-called locomotor, changes in the position or curvature of the artery. The disturbances set up in the tracing in this way are probably of a complicated nature.

(2) Fulness of the subcutaneous veins, mechanically raising the level of the tracing, may supervene very rapidly, and within the duration of a single tracing.

(3) The smaller tracings being the more reliable ones, the higher pressures should be used first, and gradually diminished, so long as no obvious deformation of the tracing is set up. This is in direct opposition to the practice of the early teachers of sphygmography.* Complete flattening of the artery by the button is not likely to occur, seeing that the pressure of the latter will diffuse itself in every direction in the watery tissues. Under the influence of the heightened tissue-tension, the artery will contract fairly evenly, whilst the blood-pressure is resisted, no longer by the arterial wall, but by the tissues around and by the spring of the sphygmograph.

The Variability of the Arterial Tracing.

Von Frey regards the sphygmograph as well suited for determinations in the small arteries—the tonograph for the larger ones only, owing to the unavoidable movements of the fluid and to the friction to which they may give rise; but whichever instrument be used it is remarkable that tracings from the same artery will be very different when taken at different points of its course, or from the same spot at different times. Frequency seems to be almost the least variable of the qualities of the pulse.

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* See O. J. B. Wolff, "Charakteristik des Arterienpulses," Leipzig, 1865, p. 19.

The size, as well as the *hardness* or maximum of tension, both decrease from the centre to the periphery. So changeable is the shape of pulse-curves that, if any comparison is to be made between tracings from different arteries, they should all be taken under identical circumstances and with as little interval as possible (*cf.* Fig. 103, p. 215).

The line of ascent and the primary summit present noticeable differences in tracings from different arteries in the same individual. The primary summit occurs, according to von Kries, in the carotid 0·05 of a second after the beginning of the tracing, 0·06 in the brachial, 0·08 in the femoral, and 0·10 in the radial.

Much attention, as will presently be seen, has also been bestowed on the exact timing of the so-called dicrotic wave. In respect of the remaining details of their configuration, any two curves may be totally different: the minute elevation in the one may correspond to a depression in the other; the primary summit may be rounded, or it may be sharp; the line of descent may be concave or rounded. Moreover, when features of two different curves do coincide, are we justified in concluding that the two like summits or depressions are really equivalent? They may be the resultants of very different wave combinations.

CHAPTER V.

VON KRIES' ANALYSIS OF THE PULSE-TRACING.

Preliminary Remarks on the Peripheral Rebound.

Von Kries' analysis of the sphygmogram is worked out strictly on the theory of peripheral wave-rebound, with the help of a comparative study of the pulse-tracing and of the tachogram.

A Peripheral Rebound obtainable in the Artificial Circulation within the Dead Body (of Animals).

Experiments of this kind, first published by Bernstein,* subsequently by Hoorweg,† and by von Frey and Krehl,‡ were previously conducted in 1882, although not published, by von Kries. The occurrence of a peripheral wave-rebound was recognised by von Kries, and by von Frey and Krehl; but the other two observers failed to obtain it, most probably owing to the unfavourable conditions special to their experiments. The positive results recorded are a strong argument in support of the probable occurrence of similar rebound-waves during life.

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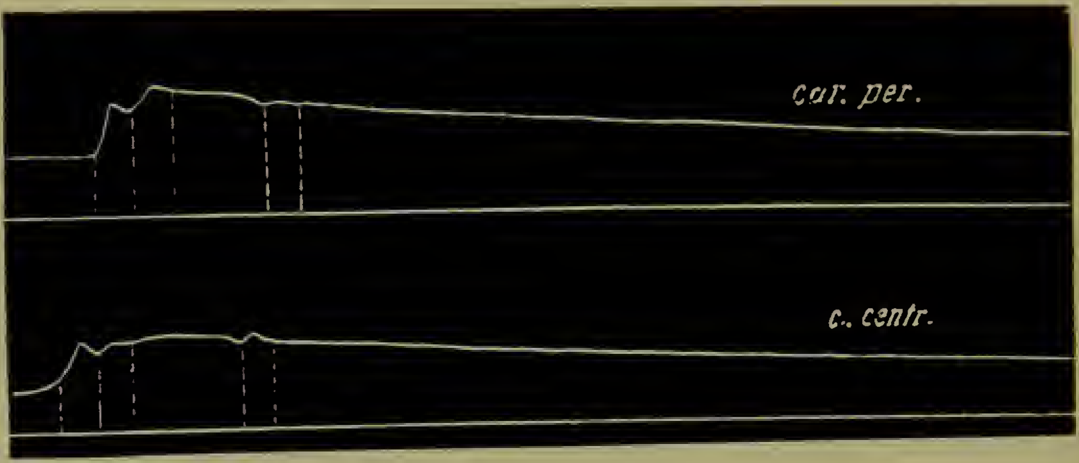
* Sitzungs berichte der Naturforschenden Gesellschaft zu Halle, 1887.
† Pflügers Archiv., bd. 46, s. 167.
‡ Du Bois Reymond's Archiv., 1890.

Hürthle's Comparative Study of Central and Peripheral Pulse-Tracings.

Hürthle,* in his comparative study of the serial summits of the carotid and of the femoral pulse-tracings, did not succeed in obtaining conclusive evidence in favour of the wave-rebound theory. According to von Kries, he appears to have overlooked the fact that any elevation due to a rebound must approach nearer and nearer to the primary apex, the nearer to the periphery the tracing has been taken.

FIG. 104.



Carotid pulse-tracings from a peripheral and from a central part of the vessel. (Hürthle, Pfluger's Arch., bd. 47.) (Reproduced from von Kries, *loc cit.*, p. 67.)

The Wave-Rebounds at the Entrance of the Medium-sized and Small Arteries, and of the Capillaries, are not of the Negative Kind.

In opposition to Grashey, von Kries contends that the wave-rebound from the capillaries is of a positive kind; and he also argues that the arterioles likewise throw back the wave as a positive one.

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* Pflüger's Archiv., bd. 47 and bd. 49.

He inclines to a belief that the wave, in passing from the larger arteries into the middle-sized ones, does not suffer any considerable positive rebound, but at any rate not any negative rebound, and that *the rate of transmission of the pulse-wave along the latter vessels rather increases than diminishes towards the periphery.*

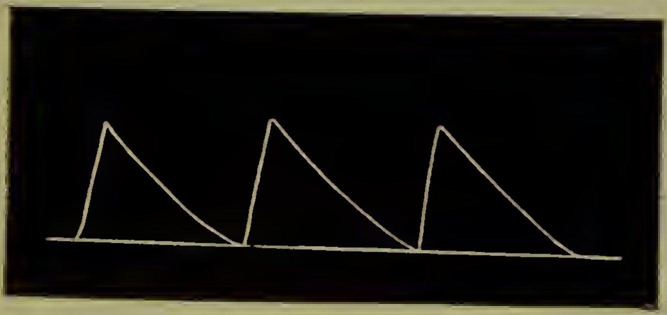
An opinion is also expressed that, in them, the aggregate increase in lumen is not, during life, as considerable as it has hitherto been estimated from observations in the dead body.

Matters are widely different in connection with the arterioles and capillaries. Their aggregate lumen progressively and largely increases. Meanwhile friction occurs in a remarkably increased proportion, so much indeed as to warrant us in expecting a positive rebound analogous to that seen at the closed end of a tube. At the same time von Kries does not allow that the evidence to that effect is absolutely convincing, and it is still conceivable that *the extraordinary dilatability of capillaries may compensate for their increased frictional resistance.*

The Slow Descent of the Down-Stroke of the Sphygmogram is due to Wave-Rebound.

The aortic systolic inflow, which causes the pulse-wave, occupies less than half the duration of the latter. From about the beginning of the dicrotic rise, or even earlier, it has entirely ceased. Why should the pulse-curve be so slow in falling? Friction,

FIG. 105.



Elementary pulse-curve from a schema (von Kries).

in a tube of the diameter of the aorta, is too slight a force to explain the delay. On the other hand, tracings taken from an elastic reservoir, distended by a periodical inflow and provided with narrow orifices of outflow, exactly imitate the pulse-curve in its elementary form—(viz., when freed from secondary elevations). In the fluid contained in a completely closed elastic balloon, the rise due to external pressure is kept up—because there is no outflow; in the reservoir mentioned above it is kept up for a longer time than the external pressure, because the greater part of the wave of pressure undergoes complete reflection at the narrow orifices.

The Wave-Rebound in its Relations to the Arterial Distribution.

Von Kries insists that in any arterial district the secondary, dicrotic, wave is to be regarded as the combination of the rebounds occurring in all other vessels throughout the body.

The study of wave-rebounds is much complicated by the extensive range of difference in the length of arteries. It may be admitted, however, that the very long and the very small arteries are in the minority; and that the greater number are included within a certain average as regards length (among these may be reckoned the arteries supplying the intestine and abdominal viscera). To this larger group the chief rebound must be attributed, which eventually supplies the dicrotic wave; and owing to its multiple origin we may expect this wave to present a broad summit. In reality, the dicrotic summit is always much less pointed than the primary.

Meanwhile the shortest arteries will have given rise to much earlier rebounds, which would be registered at an earlier stage of the pulse-curve—that is, anterior to the dicrotic wave.

The Predicrotic Waves.

Von Kries traces the occurrence, in the interval between the main summit and the dicrotic summit, of two small waves (which Landois has described under the name of " Elastic Elevations.")

These waves are very easily overlooked. If the main wave should be very pointed, they stand out as elevations ; but a very rounded summit of the pulse-wave may not allow them to be recognised, or even suspected, except by the expert.

Simultaneous study of the tachogram has led von Kries to regard the first of these as a *centripetal wave.* The second, of much less constant shape, has a *centrifugal* direction. It is to be considered as analogous in its origin to the dicrotic wave, but as due to rebounds from much shorter vessels.

In some cases alterations in the innervation of some of the vascular districts, or influences of a different kind (such as that of nitrite of amyl), may produce alterations in the size of this wave—or in its shape :—its apex, for instance, may become doubled. Von Kries has tried to prove this mode of influence by sphygmograms taken from the radial, whilst the other arm was exposed to severe cooling, and he believes that the resulting effect is more strongly marked in the predicrotic wave than in any other.

High Tensions of Peripheral Origin.

Von Kries (*loc. cit.*, p. 125) is in favour of the old view, that a slow and even fall of the line of descent with little prominence of the dicrotic wave, argues high tension ; and that low tension is indicated by a rapid descent, and a marked dicrotism. The slow fall has been shown to be due to peripheral rebounds. The greater the rebound set up as a result of a contracted state of the vessels, so much the closer will be the resemblance between the sphygmogram and the tracing obtainable from an elastic reservoir with narrow outlets, a tracing in which the fall in pressure is absolutely gradual from the apex of the wave to the foot of the next upstroke.

The instance of the local pulse-modifications observed in the arm when raised teaches us not to draw too hasty a conclusion from the pulse-tracing from any single artery, as to the condition of others. Above all, it would be rash to apply the observations made in the vessels of the limbs, and in the cutaneous vessels, to the visceral districts.

It is very doubtful whether the strong dicrotism observed in feverish states, indicates a general relaxation of all the vessels. The disappearance of dicrotism at the height of the nitrite of amyl reaction substantiates this doubt.

The variety of pulse-tracing which is usually ascribed to high tension, may be brought forth by local conditions of the limb ; but it may also be a result of multiple and extensive rebounds, occurring within shorter vascular territories.

CHAPTER VI.

VON KRIES ON SOME ARTIFICIAL OR EXPERIMENTALLY PRODUCED MODIFICATIONS OF THE PULSE-TRACING.

I. The Changes in the Pulse due to Raising the Arm.

On raising the arm the most conspicuous effect, easily demonstrated by connecting the plethysmograph with the flame of an ordinary gas lamp provided with a graduated cylindrical glass chimney, is an *increase in the size* of the pulse.

The plethysmogram (volum-puls) of the forearm (the instrument being in this case charged with air instead of water) shows an increase in the size of the oscillations.

The tachogram likewise yields increased values, whether the observation be confined to the hand or include the middle of the forearm.

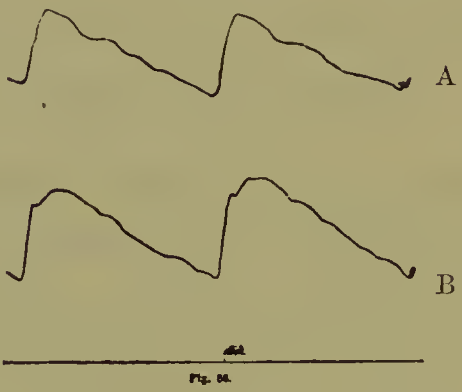
Marey explains the greater amplitude of the sphygmogram as being due rather to the increased excursions of the arterial wall than to any real increase in pressure.

Von Kries, working with a transmission sphygmograph, the movements of which were registered on a much enlarged scale by photography, found the leading features of the two modifications of the pulse-curve to be:

With arm dependent: Sharp rise and a rather quick fall of the tracing, dicrotism marked;

With arm raised: Slow rise with anacrotism, slow fall of the line of descent; dicrotism very feebly marked. These points are illustrated in the annexed tracings, by von Frey (*loc. cit.*, p. 220).

FIG. 106.



Tracings from the radial (von Frey). A: With arm dependent; B: With arm raised.

It is noticed that in the tachogram the drop which immediately follows the main rise occurs more slowly with raised arm, giving to the wave summit greater breadth.

On the other hand, the drop is much more considerable, showing that the wave is much more strongly reflected in the raised position.

It is regarded as certain that the pressure is much lessened in the vessels of the raised hand, and that the capillaries are emptied of much of their blood.

Why is the Systolic Wave slowed in the Raised Arm?

Von Kries briefly considers the possible influence of stretching on the diameter of the artery, and of a smaller diameter on the shape of the wave. More stress is laid on the influence of the *short-circuit rebounds,* originating at the level of the shoulder, and on their centrifugal course, tending to delay the main wave and to broaden its tracing.

The increased dimensions of the tachogram are to be explained in connection with the relaxed condition of the artery and the slackened speed of the wave.

The small anacrotic elevation seen in the sphygmogram is really the main summit. The higher summit is that of a powerful rebound made up not only of the backward rebound from the hand, but also of the centrifugal rebound from the whole arm.

The lessened degree of dicrotism observed is a direct result of the sustained height of the curve.

II. MODIFICATIONS OF THE PULSE DUE TO THE APPLICATION OF COLD OR OF WARMTH TO THE ARM.

Cooling the arm lowers the sphygmographic oscillations in a marked degree.

Tachograms, taken by means of a plethysmograph provided with an alternating hot and cold water supply, also show great differences.

At the same time, however, modifications in shape are much less noticeable than in the case of raising and lowering the arm.

Probably the influence of the cold application is also exercised on vessels of a larger size above the seat of the application. This would explain alike the diminution of the oscillations of pressure, and the indistinct character of the phenomena due to wave-reflection. The predicrotic wave is apt to be very prominent, both in the pulse-tracing and in the tachogram. This is probably due in part to rebounds occurring at a higher level in the arm.

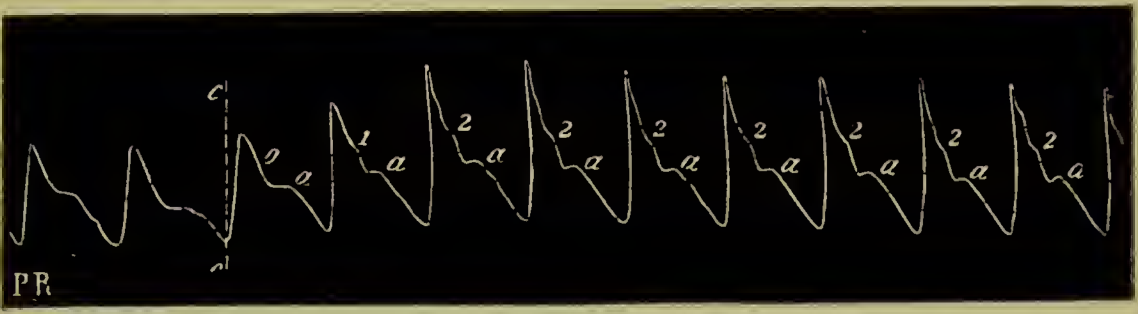
Warmth causes much less departure from the ordinary type of tracing. The line of descent falls rapidly at first, and subsequently much more slowly.

III. MODIFICATIONS RESULTING FROM CHANGES INDUCED IN DISTANT VASCULAR DISTRICTS.

Alterations in the vascular conditions of separate districts influence the radial pulse only in proportion to the effect which they take upon the contents of the first part of the aorta. But they also tend to set up (as in the case of the occlusion of large vascular areas) vaso-motor compensations of a highly complex character. Nevertheless, von Kries does not agree with Landois that the distant influences are unable to modify the pulse-trace. By alternately tightening or loosening a ligature placed round the abdominal aorta, very striking differences are set up in the carotid sphygmogram, and the effect is yet more pronounced in the tachogram.

If, as practised by Marey, the artery under examination be obliterated lower down, the fact that the dicrotic wave remains perceptible above is not an adequate proof of the centrifugal nature of the wave, as alleged by Marey.

Fig. 107.



Radial tracing (Marey, *loc. cit.*, p. 287). From the moment C, when compression was made below the sphygmograph, "there is an increase in the size of the pulsations, as well as in that of their systolic undulations 1, 2, &c., and of their diastolic undulations *a*, *a*, &c."

> "Alors en effet, l'onde centrifuge ne pourrait franchir le point comprimé, et, la réflexion se faisant au lieu même où l'artère est explorée, il n'y aurait plus de séparation entre l'onde centrifuge et l'onde centripète ; on aurait seulement une onde unique mais plus haute qu'à l'état normal. Or, en comprimant la radiale au poignet, audessous du point d'application du sphygmographe, on ne supprime pas la deuxième onde ; celle-ci est donc centrifuge comme la première."

Since the vessel above remains in communication with the ulnar artery, which is still capable of conveying a reflux wave, and with the aorta to which reflux waves from other parts may have been transmitted, the wave in question might yet have been a centripetal wave. If the effect of distal closure of an artery is to be studied, the observations should be made, as in the case of the radial when the arm is raised, within the vascular distribution of the artery submitted to the modifying influence.

CHAPTER VII.

THE DICROTIC EVENTS, AND DICROTISM; AND THE PREVAILING THEORIES AS TO ITS ORIGIN.

A COMPLETE history of the theories on dicrotism would be too large a subject for these pages. Let us take it at its present stage. The choice lies to-day between two views, representing the two systems of sphygmology:

(1) Marey's original view that the *dicrotic rise was a wave rebounding from the closed central end of the aorta*, subsequently abandoned by physiologists, has been taken up and ably defended by von Kries and von Frey.

(2) Meanwhile the "*fluid inertia theory*" has been widely adopted, although the conditions most favourable to this—viz., a rigid system of tubes—are not those distinctive of a healthy arterial system.*

(3) Another less important view may find mention at this place. Those who ascribe the sigmoid closure

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* This doctrine has led Roy and Adami (*Practitioner*, vol. xlv. 1890) to state in opposition to previous teachings that the dicrotic pulse is peculiar to high arterial pressures, because these tend to render the arterial walls rigid.

to *a reversal of the aortic stream,* explain the dicrotic fall and the dicrotic rise as expressions of this temporary reversal and of the ensuing return of the current to its original direction. Since this view is bound up with the assumption of an actual reflux of blood into the ventricle—a reflux which in the case of an exaggerated dicrotism would presumably be almost as considerable as the ventricular output—we need only ask by way of comment, Why is not a regurgitant murmur audible ?

THE DICROTIC WAVE ; AND ITS FEATURES AS FAR AS KNOWN.

There is no difficulty in most tracings in identifying the dicrotic wave. Authors, in their remarks, clearly refer to the same object.* The only doubt is as to its nature, its cause, and its mechanism.

The Direction and Character of the Dicrotic Wave. Its Analogy with the Primary Wave.

(1) The wave is a *positive* wave because it produces a distinct elevation of the trace. (2) From Roy and Adami's remarks we may conclude that they regard the wave as *centrifugal,* although they do not give their reasons. The same view is explicitly stated by von Kries and von Frey, and based upon demonstration (see p. 253). (3) Since the wave is detected even in tracings from the aorta, we may regard its

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* Roy and Adami use in speaking of the dicrotic wave the expression "Post-dicrotic wave," which by most authors is reserved for the elevation which is apt to follow the wave in question.

appearances in the various arterial tracings as expressions of one and the same wave. In all these particulars, therefore, as a positive, as a centrifugal, and as a continuous wave, the dicrotic resembles the primary wave.

The Position of the Dicrotic Wave: Is it Constant or Variable?

The dicrotic wave occupies a definite place in the series of events belonging to the pulse-wave, and therefore, a definite position in the tracing. Some go so far as to say that the time relation between the primary and the dicrotic wave is identical in the same individual, whichever be the artery supplying the tracing. Thus Marey, Grashey, Hoorweg (in man), and Hürthle (in the dog), have failed to obtain any variation in the time of onset of the wave. Other observers, however, including Landois, von Kries, and Edgren, have been able to trace a slight difference in the time of the wave at spots differing in their distances from the heart.

Landois* found the interval between the beginning of the curve and the dicrotic summit on the average equal to: ·345 of a second in the carotid; ·40 of a second in the axillary; ·39 in the radial; ·60 in the femoral; and ·52 in the dorsalis pedis.

Von Kries finds ·34 for the carotid; ·39 for the brachial; ·40 for the radial; ·48 for the dorsalis pedis; ·45 to 50 for the femoral. Time measurements on the tachogram lead to similar results.

Edgren's figures are analogous to these, but the differences are smaller, ·29 of a second for the radial and carotid, ·31 for the femoral artery.

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* Quoted by von Frey, *loc. cit.*, p. 162.

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Landois concludes that the farther from the heart it is traced, so much the later will the dicrotic wave appear in the sphygmogram; but his facts, it is pointed out by von Kries, do not quite bear out this construction. For instance, the relative delay in the arrival of the dicrotic wave into the dorsalis pedis artery, as compared with the carotid, is really smaller than would be expected on the assumption that the delay was determined by distance. The minute attention bestowed by von Kries upon comparative measurements renders his results and his criticisms especially weighty.

Thus, although von Kries almost entirely agrees with Landois in his timing of the dicrotic summit, he does not subscribe to the conclusion drawn by that author; nay, he holds that the difference in time is much greater in appearance than it is in reality, and that it is for the greater part dependent upon the points selected for measurements in the tracings. The earliest measurements, those by Landois, utilise the beginning of the primary wave and the summit of the dicrotic.

Von Kries repeated these experiments with the results stated; but in addition he determined the distances between the beginning of the primary wave and that of the dicrotic wave, a proceeding also employed by Hürthle and by Hoorweg.

Reckoning (in hundredths of a second) from the beginning of the primary wave, in tracings obtained by means of the tachograph, von Kries found the following delays:

For the primary summit:	
at the femoral	0·10
at the middle of the calf	0·09
at the middle of the upper arm . .	0·09
at the middle of the forearm . . .	0·08
For the beginning of the dicrotic rise:	
at the femoral	0·27
at mid-calf	0·25
at the middle of the upper arm . .	0·25
at the middle of the forearm . . .	0·25

For the summit of the dicrotic rise :

at the femoral	0·43
at mid-calf	0·46
at the middle of the upper arm	0·38
at the middle of the forearm	0·35

From these experiments von Kries draws the important conclusion that *the beginning of the dicrotic rise bears an almost constant relation to that of the primary wave in all arteries, although the summit of the dicrotic wave occupies very various positions.*

The Velocity of the Dicrotic Wave.

This constant relation in time between the primary and the dicrotic wave leads von Kries to conclude that the dicrotic wave travels, not only in the same direction, but with the same velocity, as the primary wave, suffering hurry or delay in the same proportion as the latter. He is inclined to lay little stress on an argument, which has been quoted also by von Frey, to the effect that since small waves travel less rapidly than large ones, the local accelerating or retarding influence, special to each of the various arteries, must tell unevenly upon the primary and the dicrotic wave, or upon dicrotic waves of different sizes.

The Shape and Size of the Dicrotic Wave and their Local Differences.

It may be said of the dicrotic wave that, in sphygmograms, we know it by its site and by its surroundings, rather than by its shape and size. Than the latter nothing could be more variable—in some tracings insignificant, in others almost equalling that of the primary wave. Its shape also varies considerably. Von Kries' determinations of the distance of the beginning, as well as of the summit of the dicrotic wave, has provided us with a mathematical demonstration of differences in size, which otherwise were likely to be overlooked.

Expressed in hundredths of a second, the primary wave was separated from the beginning and from the summit of the dicrotic wave respectively by the following intervals:

For the brachial artery, ·27 and ·39 (a difference of ·12).

For the radial artery, ·28 and ·40 (a difference of ·12).

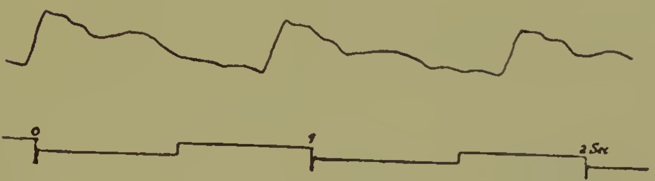
For the femoral artery, ·33 and ·45 to ·52 (a difference of ·12 to ·17.

For the dorsalis pedis artery, ·32 and ·48 (a difference of ·16).

The tachograph gave analogous results.

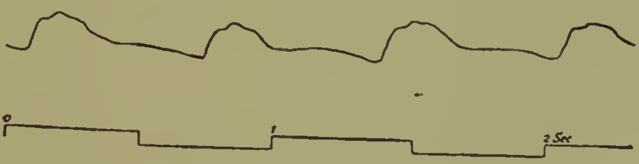
The upshot is, that the *dicrotic wave in the lower extremity is much more flattened and long drawn*

FIG. 108.



Von Kries' sphygmogram of the brachial pulse. (Reproduced from von Frey, *loc. cit.*, p. 168.)

FIG. 109.



Femoral tracing from the same subject, showing a later and broader dicrotic summit than the brachial tracing.

than it is in the upper limb and in the carotid. This is readily verified by referring to the tracings taken from the extremities of healthy subjects by other observers. Like von Kries' sphygmograms, those taken from the lower extremity will show a later dicrotic summit than those from the upper.

The fact that, the farther any waves travel within elastic tubes, so much the more flattened do they become, does not fully explain the peculiarity mentioned, and fails to help us in the elucidation of other questions connected with dicrotism.

The same artery will yield very different shapes of the dicrotic wave in different individuals, all healthy. As to the pathological variations, there is no limit to them. Even a slight indisposition may, as illustrated in Roy and Adami's paper, produce a great change in this respect. The most striking form of pathological dicrotism is that obtained from fully dicrotous or hyperdicrotous pulses. It illustrates the extent to which types of dicrotic waves may vary.

CHAPTER VIII.

THE "INERTIA" THEORY OF DICROTISM.

THIS theory has found its latest exponents in Roy and Adami, whose views (fully set forth in the *Practitioner*, Feb.–July, 1890) are easily accessible to the reader, and need here but a brief description.

I. *Normal Dicrotism.*—This is apt to vary within wide limits, but is generally represented in the downstroke by a ledge rather than by a notch, and by a shoulder rather than by a rise.

(*a*) The normal *dicrotic notch* is to be regarded as a negative wave due to the inertia of the blood driven into the aorta. Its depth would increase with the velocity of the output, and with the abruptness of its cessation*; and also with the degree of rigidity of the arteries—and, therefore, with the degree of intra-arterial pressure from which their rigidity is apt to arise. The negative wave travels onwards.

(*b*) In immediate succession comes the positive "post-dicrotic" wave, also centrifugal, the varying height of which influences the apparent depth of the notch. This wave is likewise attributed to inertia, although not exclusively so. "Its form can also be affected by the sudden relaxation of the ventricular wall at the end of systole."

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* *Practitioner*, vol. xliv. p. 416.

(*c*) The late and inconstant small positive wave following the dicrotic elevation is also regarded by Roy and Adami as a wave of inertia.

II. *Excessive Dicrotism.*—(*a*) An increased depth of the notch would be most favoured by the conjunction of (1) a small and abrupt ventricular output, and (2) a raised intra-arterial pressure*; since both would favour the wave of inertia.

(*b*) The tracings taken in sthenic fever, or in the sthenic stage of exhausting fevers, show that marked dicrotism may co-exist even with a larger ventricular output than normal, provided that, thanks to a diminished resistance to the peripheral outflow from the arteries, the outflow be rendered sufficiently abrupt.

(*c*) Other tracings† also supply evidence that a typically dicrotic pulse-trace, of the kind usually called a low-tension pulse-curve, may be obtained in cases where the blood pressure‡ in the systemic arteries is little if at all below the normal.

The Conditions Leading to an Increased Depth of the Dicrotic Notch.

A normal amount of dicrotism is that which may be obtained by momentarily holding the breath with open glottis. The tracing then shows in most cases no positive rise of the lever after the notch. The tracing (Fig. 26, *loc. cit.*, p. 421) shows various depths of the notch in connection with varying pressures.

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* The depth of the notch would be increased by high intra-arterial pressures, inasmuch as they tend to make the vessel walls more rigid. In this connection Roy and Adami dwell upon the contradiction which exists between the alleged causation of dicrotism by low pressures and the recognised function of arterial elasticity, the purpose of which is to transform the intermittent into a continuous current.

† *Practitioner*, vol. xlv. p. 23.

‡ Under the above statement may be understood the minimum arterial pressure.

The greatest depth in this case coincided with a high intra-thoracic pressure, equal to 42 mm. mercury, the effect of which would be to lessen the systolic charge. The mean arterial pressure rises at the same time somewhat above the normal. Another feature of this phase of the tracing was the total absence of the outflow-remainder (pre-dicrotic) waves. In other words, the outflow from the ventricle had been completed coincidently with the rapid contraction of the musculi papillares, and had therefore ceased before the dicrotic rise. The increased depth of the dicrotic notch is explained by Roy and Adami in connection with this rapid emptying of the ventricle, together with the heightened pressure set up within the arterial system.

As the breathing is resumed, the abdominal veins fill again, the systolic charge increases, and the arterial pressure diminishes. The depth of the dicrotic notch then lessens, although the greater part, if not the entire outflow, is still brought about by the contraction of the papillary muscles. In the third stage, the waves rise to a considerable height, owing to the increased intake and output. The outflow-remainder wave asserts itself once more.

Roy and Adami regard the mechanism of the heart-beat as beautifully adapted for a rapid outflow with a minimum of inertia vibrations, because the maximum of pressure occurs early in systole, and the pressure is falling fast at its termination. But this saving of inertia vibrations is only to be secured when the ventricular output, the arterial pressure, and the peripheral resistance maintain mean values.

In conclusion, "the depth of the dicrotic notch is increased by any cause which diminishes the volume of blood which is thrown out by the ventricle at each contraction, and also by any cause, which, *cæteris paribus*, raises the pressure within the systemic arteries." "A pulse-wave with greatly increased dicrotism may occur with intra-arterial pressures at or above the normal."

Roy and Adami consider the nature of the heart's action as being of great importance "as a factor in the production of increased dicrotism." A short sharp systole with rapid propulsion of the blood into the arteries will lead to a correspondingly sharp and energetic rebound or reactionary wave—"that is to say, to increased depth of the dicrotic notch."

The Increased Dicrotism of Sthenic Fever.

After referring to changes in the tracing which seem to have been premonitory to an attack of coryza, Roy and Adami mention among the peculiarities of the dicrotic pulse in sthenic fever the great height of the wave, indicating a large ventricular output, and probably an increased rapidity of the shortening of the myocardium.

As a result of the abrupt and forcible ventricular emptying, occurring mainly during the time of the active depression of the mitral flaps, the inertia vibration would be increased and would produce an increase in the post-dicrotic rise. Meanwhile, the rapidity of the fall of the wave down to the notch indicates great freedom of outflow from the arteries.

All these features may be obtained, at least temporarily, by taking a deep breath, which increases the blood within the heart without increasing the peripheral resistance.

The authors conclude that " diminished resistance to the outflow of blood from the arteries, by allowing the outflow to finish at an early period in the systole, may lead to marked dicrotism, even although the volume of blood expelled from the heart at each contraction is greater than normal ; although it is possible that this may, in certain cases, be due to increased rapidity of ventricular contraction."

The febrile curve described may pass by easy gradations into the so-called low-pressure dicrotic curve.

From these remarks it may be gathered that certain differences are admitted to exist between the increased dicrotism of high and of low pressures.

CHAPTER IX.

THE "REBOUND" THEORY OF DICROTISM.

Von Kries and von Frey support the notion of a to-and-fro reflection of the systolic wave, according to which the dicrotic wave would be merely a third entry on the sphygmographic stage of the original heart-wave. They base this theory on a searching analysis of the sphygmogram and of the tachogam.

Von Kries reviews the whole question in the following way:

(1) In the first place, does the wave start from the cardiac end of the aorta, or from the periphery?

(2) In the second place, if central in its origin, is it due:

- (*a*) to the mode of cardiac contraction?
- (*b*) to the sigmoid valve closure?
- (*c*) to the displacement of the heart?
- (*d*) or to an elastic stretching of the aorta?

(1) The first question is answered by the tachograph, which demonstrates the peripheral origin of the wave.

The origin is peripheral, because the wave is preceded in the tachogram by a deep depression, indicating the passage of a positive wave of pressure in a backward direction. Thus this dicrotic wave would be a twice-reflected wave (once at the periphery and once at the semilunars). This corresponds with Marey's "Rebondissement."* But Frédéricq, Hoorweg, and Hürthle reject a peripheral reflection.

The tachograph, which records an event almost identically coinciding in time with the sphygmographic dicrotism, has in like manner enabled von Kries to demonstrate the centrifugal nature of the dicrotic wave. He draws attention to the dicrotic summit being slightly earlier in the tachogram than in the sphygmogram †: this is taken to be a proof of the centrifugal direction of the dicrotic wave.

The tachograph not being applicable to the arteries of the trunk, we are restricted in connection with them to other methods of proof, which are at least confirmatory; thus, according to von Frey, Chauveau and Lortet's hæmodromographic tracings of velocity in the carotid of the horse show considerable agreement with the results elsewhere obtained with the tachograph; again, in artificial circulation experiments in animals just killed, the positive reflection of each positive oscillation of pressure may be traced up with great regularity into the aorta (von Frey and Krehl, *Du Bois Reymond's Archiv.*, 1890, s. 31).

The failure of Bernstein and Hoorweg is considered to be explained by their interposing some 10 metres of indiarubber tubing, and by their diluting blood with NaCl solution, which does not give rise to the same reflection of waves as defibrinated blood, a difference which von Frey illustrates by experiments and tracings.

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* This view would also agree with the statement of Roy and Adami: "A short sharp systole with rapid propulsion of the blood into the arteries will lead to a correspondingly sharp and energetic rebound or reactionary wave—that is to say, to increased depth of the dicrotic notch" (*Practitioner*, vol. xlv. p. 23).

† Von Frey notices that the dicrotic summit is followed in the tachogram by a drop which he regards as analogous to the deep drop after the primary summit; he thinks that another rebound-wave is latent in this situation.

As early as 1865, Onimus and Viry derived, from the occurrence of pulsation in the veins in C. Bernard's chorda-tympani stimulation experiments, the notion that the normal arterial rebound was due to the blood-cells in the capillaries. They found that the same pulsation could be set up in the veins by diminishing largely the number of the corpuscles by venesection.*

(2) Supporters of the view that the origin of the dicrotic wave is central, are met with objections arising from the subject itself:

Cases of heart disease may differ widely in most important respects. Some are cases of valvular disease, others of hypertrophy, others of dilatation, etc. Yet their pulses may preserve, as regards the dicrotic wave, a general uniformity, which is in contrast with their functional inequalities. On the other hand, the instances in which dicrotism assumes unusual proportions, are often precisely those in which little or no organic defect is traceable in the heart or in the vascular system.

Theories which ascribe the origin of the dicrotic wave to causes having their seat at, or near the heart, suffer in common from the difficulty of explaining away these remarkable facts.

We cannot follow von Kries into a discussion of the various theories enumerated under (*a*), (*b*), (*c*), and (*d*), with the exception of the more important one.

ARGUMENTS AGAINST THE "SIGMOID VALVE-CLOSURE" THEORY.

Von Kries has put very strongly the objections to the view which attributes the wave to the effect of the closure of the sigmoid valve. This theory practically presupposes a reflux into the ventricle prior to complete closure of the valve. Hoorweg, Fick, and Hürthle, all three adopt the theory of reflux, and Hürthle has even endeavoured to show experimentally, that a reflux of 0·5 cm. of blood will suffice to close the pulmonary valves.

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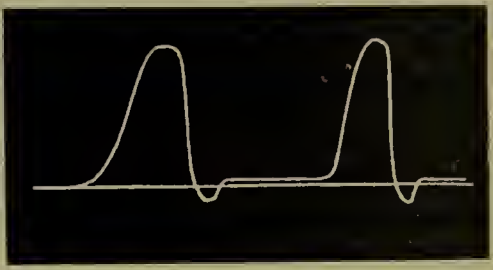
* *Journal de l'Anat. et de la Physiol.*, 1866, p. 148 (quoted by von Frey, *loc. cit.*, p. 177).

If this is to be regarded as the normal reflux corresponding to a normal dicrotic wave, what will be the amount which must regurgitate in order to produce dicrotic waves of the size seen in absolute dicrotism and in hyperdicrotism? Judging from the size of some of the dicrotic waves, this would mean the reflux into the heart of a very large proportion of its systolic output—and the occurrence of a regurgitant aortic murmur would be quite unavoidable.

FIG. 110.



Von Kries schema illustrating the behaviour of intra-aortic pressure which would correspond with the alleged reflux (*loc. cit.*, p. 74).

We should not lose sight of the fact that, at the moment preceding closure, the velocity of the blood immediately above the valves as well as below them, is *nil*, whilst the pressure is one and the same in the sinuses of Valsalva and in the ventricle. The negative phase of pressure is not reached in the ventricle until the valve has separated the cavity from the high-pressure contents of the aorta.

Martius* admits a "Verharrungszeit," during which the valves are in unstable equilibrium, the ventricular output having come to an end, whilst suction has not yet been set up by expansion of the ventricle.

At that moment a very feeble force would suffice to close them, since they would have been already floated up into position (*gestellt*), and almost into contact. Therefore, with the advent of diastole; there would be no back-leakage, and the second sound would be produced by their tension at the moment when the ventricular pressure suddenly began to fall.

Martius suggests that most probably Ceradini's eddies † (*Wirbel*) are the small force in question.

Von Kries regards the return-wave, reflected from the periphery, as perhaps sufficient for the purpose. According to this view a close relation would exist between the rebound-wave, the valve-closure, and the dicrotic wave.

Von Frey remarks, that the causes of dicrotism are probably various, and that it would be premature to formulate any definite theory as to its mode of production. Mere frequency of rate, mere elevation of body-temperature, mere lowering of arterial tension ‡—none of these are constant causes.

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* "Epikritische Beiträge zur Lehre von der Herz Bewegung" (*Zeitschrift fur klin. Med.*, bd. 19).

† According to Ceradini eddies are set up by the axial stream from the ventricle, in the more stagnant blood filling the sinuses of Valsalva.

‡ Von Frey insists that this low tension is not to be confused with low arterial pressure (*cf.* p. 43).

When the cord is divided in animals the vessels dilate, the tracings lose their definition, and the dicrotic rise becomes difficult to identify. Stimulation of the cord will at once bring them into view again. These same experiments, however, afford demonstration of the fact that the distinctness of the secondary waves, and in particular of the dicrotic wave, does not remain constant under any given pressure, but is apt to vary, though the heart-beat and blood-pressure may have remained the same.

In short, there is not a single fact pointing to low tension as a necessary factor: whilst, in von Frey's estimation, vaso-motor innervation has a large place in the ætiology of dicrotism.

From all this, the conclusion may be drawn that dicrotism may arise from various causes. We know this much, that in fever, whilst the blood-pressure may rise and the internal vessels may undergo constriction, the superficial arteries and capillaries are in a state of relaxation so long as dicrotism is actively proceeding. And von Frey is almost tempted to state that *dicrotism will arise whenever cutaneous hyperæmia sets in together with strong and quick arterial beat, in subjects presenting normal or raised arterial pressure.* Even this rule, however, has its exceptions.

CHAPTER X.

VON KRIES' ANALYSIS OF THE DICROTIC WAVE.

The Centrifugal Direction of the Dicrotic Wave.

In order to demonstrate the centrifugal direction of the dicrotic wave, it is necessary to determine at any one spot the behaviour of the pulse-wave and of the "velocity-wave." The latter may be mathematically evolved, as shown by Fick, from the inflow and outflow curve or plethysmogram, which he was also the first to draw, and which is supplied by Mosso's hydro-sphygmograph. The tachograph[*] supplies the "velocity-curve" without so much trouble. In this curve also the dicrotic elevation is represented, sometimes very slightly in advance of the sphygmographic rise, but usually coinciding with it. Had the direction been a centripetal one, the tachogram would have shown a fall instead of a rise.

The following figures give the delays, in hundredths of a second, from the beginning of the primary wave to the beginning and to the apex of the dicrotic elevation, in the tachogram and in the sphygmogram respectively :

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[*] Von Kries, "Über ein neues Verfahren zur Beobachtung der Wellenbewegung des Blutes," *Du Bois-Reymond's Archiv.*, 1887; also "Studien zur Pulslehre," 1891, p. 143.

Time of the Onset and of the Apex of the Dicrotic Rise.

I.—In the Tachogram; II.—In the Sphygmogram.

I.

In femoral	onset	27	apex	43	($\frac{1}{100}$ sec.)
mid-leg	,,	25	,,	46	,,
mid upper arm	,,	25	,,	38	,,
mid forearm	,,	25	,,	35	,,

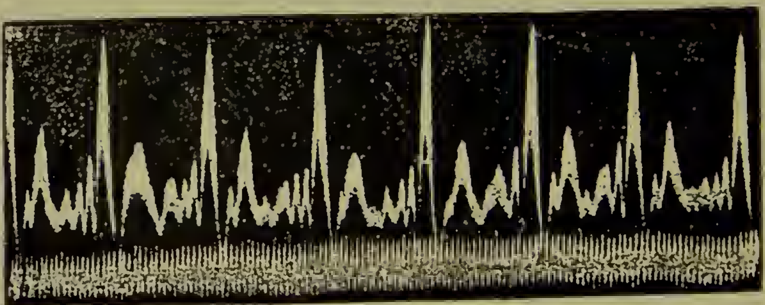
II.

In femoral	onset	33	apex	45–50	,,
dorsalis pedis	,,	32	,,	48	,,
brachial	,,	27	,,	39	,,
radial	,,	28	,,	40	,,

The Origin of the Dicrotic Wave.

Its direction having been proved to be centrifugal, the question remains—where does the dicrotic wave

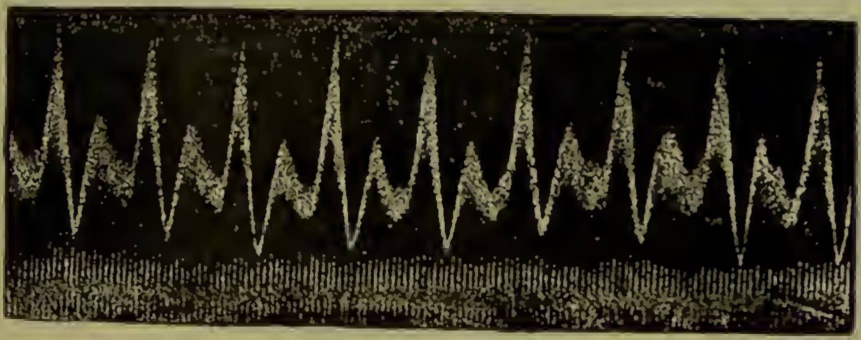
Fig. 111.



Von Kries' tachogram taken from the middle of the upper arm. (Reproduced from von Frey, *loc. cit.*, p. 168.)

arise? Does it originally start from the heart, or from the periphery? This is again answered by the tachogram. Whilst in the sphygmogram, the lever, having reached the highest point of the main upstroke, gradually subsides towards the level of the dicrotic notch, the flame of the tachogram records a very different course. Immediately after the main apex, it presents a sheer drop to a very low level, the lowest in the whole tracing. This signifies that, whilst the pressure is little diminished, the velocity suffers a great check—and this combination has been shown to indicate the passage of a positive wave in a reversed or centripetal direction. A rebound of this magnitude must obviously force its way back as far as the origin of the aorta; and finding the sigmoid valves closed, must be once more reflected towards the periphery. Whatever other influences may contribute their share to the result, an adequate link is thus established between the two centrifugal waves (the systolic and the dicrotic). Moreover, this intervening centripetal and positive wave affords the

FIG 112.



Von Kries' tachogram taken from the upper part of the thigh in the same subject. (Reproduced from von Frey, *loc. cit.*, p. 168.)

desired explanation for the continued high pressure in the arteries during the early portion of the sphygmogram.

THE DICROTIC SUMMIT.

The Influence of Distance from the Heart on the Position of the Apex of the Dicrotic Wave.

Hoorweg found in man, and Hürthle in animals, that varying distances made no change in the position of the summit. Von Kries agrees with Landois and with Edgren that it occurs later in the more remote arteries.

Hürthle and Hoorweg measured the distance between the beginning of the main wave and that of the dicrotic elevation, whilst Landois' measurements extended to the dicrotic summit: there lies the cause of the discrepancy. Von Kries' determinations have shown that in all pulses the dicrotic rise begins nearly at the same point, but that the relative position of the summit varies considerably.

Why is the Dicrotic Summit Broader in the Lower Extremity.

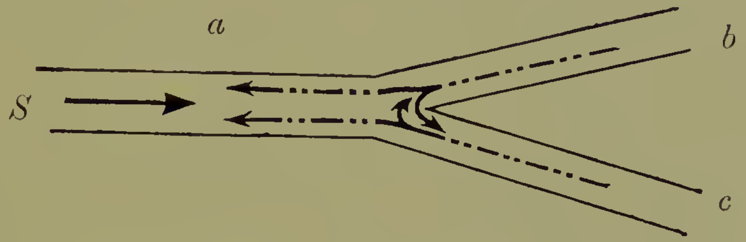
Landois' explanation is stated by von Kries to be based on the assumption, already criticised as "untenable," that the shape of the wave in any part of the body is mainly governed (under the influence of reflection) by the local vascular configuration of the part. Far from this being the case, the dicrotic wave is the expression of a secondary maximum of pressure, set up in the aorta as a resultant of rebounds from all parts; and it must follow the primary wave at about the same interval in all arteries. Landois' figures fail to establish a strict correspondence between the delays in the summit and the length of individual arteries.

The fact that small waves travel more slowly than larger ones and that, after a long journey, their summit gradually becomes blunted, is also an insufficient explanation.

Von Kries turns to a fresh quarter for an answer to the problem.

An artery *a*, bifurcating into branches *b* and *c*, of even size and of even length, receives from them simultaneous rebounds of the systolic waves, which ascend in it as a single wave.

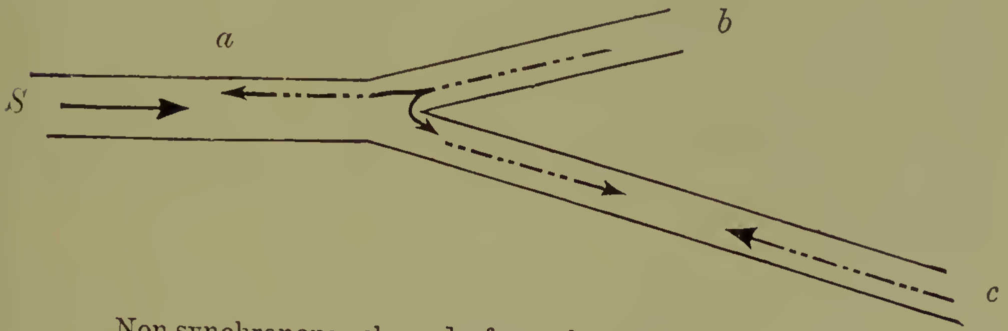
FIG. 113.



Synchronous rebounds, of a systolic wave *S*, from the periphery of two equal arterial branches. These ascending rebounds combine. The descending rebounds (into *b* and *c*), being equal and opposed, are neutralised. (Modified from von Kries, *loc. cit.*, p. 83.)

It is to be noted that the rebounds from *c* into *b*, and from *b* into *c*, which are part of the same process, mutually destroy one another.

FIG. 114.



Non-synchronous rebounds from the periphery of branches of unequal length. (Modified from von Kries.)

Should the two branches be of uneven length, the rebound from the shorter one *b* will be the first to return into *a*, and at the same time into *c* also.

The resulting effect on the shape of the reflected wave must be obvious. Whenever an important vascular supply of great extent, but of short length, is given up above the origin of a long vessel, there will be reduplication, or at least broadening, of the summit of the wave reflected from the longer artery.

As a plausible hypothesis, von Kries suggests that the mesenteric rebound, and especially that portion of the rebound which is reflected down the abdominal aorta, may be competent, not only to broaden the dicrotic summit of the femoral tracing, but to set up, within that vessel, that high systolic pressure which has already been mentioned as much in excess of that within the carotid.

The Conditions favouring a Marked Dicrotism.

The chief condition for a prominence of the dicrotic event in tracings is, according to von Kries (*loc. cit.*, p. 110), a strong fall of pressure, immediately following the main summit. Whenever the centripetal rebound inserts itself between the main wave and the dicrotic wave, which are both centrifugal, pressure is maintained during the interval between them.

Strong dicrotism will therefore arise in those arteries whose channels are widened, whilst collateral arteries remain in a condition capable of producing strong rebounds.

On the Influence of Nitrite of Amyl on the Pulse-Tracing.

Von Frey reports that nitrite of amyl is credited with very different results by different observers. Thus, Schweinburg* instead of finding, with Lauder Brunton, a depression of the blood-pressure in animals, discovers a decided rise in animals as well as in man, and never any loss of pressure. These results are confirmed, so far as they relate to man, by von Maximowitsch and Rieder,† the rise being as high as fifty per cent. during the stage of arterial excitement and flush. Von Frey does not possess a key to this contradiction between recognised authorities.

According to von Kries, the effects produced by nitrite of amyl are multiple, and occur in a definite sequence, as may be demonstrated by a continuous series of tracings. (See Fig. 115.)

One of the early results of the inhalation is a diminution of the dicrotic wave, almost amounting to its suppression. A later result is a great and rapid fall of the lever, immediately after the main summit, almost to the base-line, from which the dicrotic elevation then begins its rise. The dicrotic wave is blunt and broad, and the second predicrotic elevation is blended with it. This is the fully developed stage of the vascular reaction. The pulse rate has risen considerably and the tracings have diminished in size.

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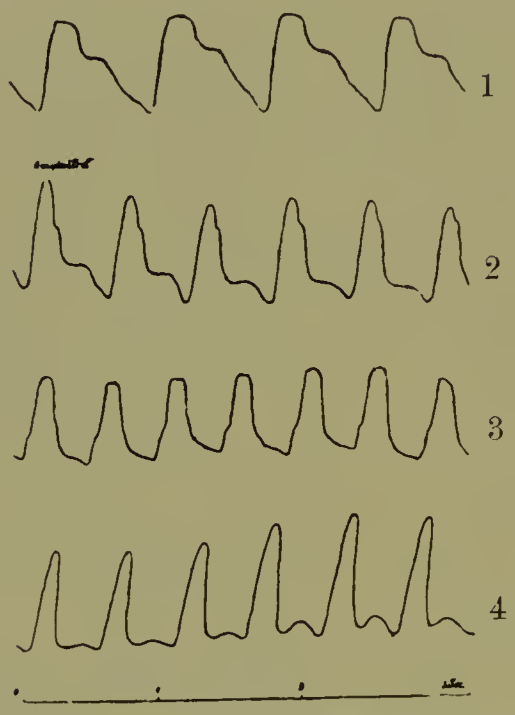
* *Wiener Med. Presse*, 1885.

† *Arch. f. Klin. Med.*, bd. 46, s. 365, 1890

On the contrary, the tachogram shows larger waves in spite of the rapid heart-rate. The predicrotic elevation is absent—and the dicrotic wave is, as, in the pulse-trace, altered and broadened, but not suppressed as in the latter.

FIG. 115.



Radial pulse (1) before ; (2) immediately after, inhalation ; (3) strong beating in the carotids ; (4) cutaneous flush, and recovery. (Reduced from von Frey, *loc. cit.*, p. 232.)

Von Kries suggests an easy explanation for this sequence of events. We may assume that, owing to the high degree of dilatation of large arterial districts, the peripheral rebound is almost extinguished within them, the relaxed arterioles allowing the capillaries to be strongly filled.

Nevertheless, the arm does not lose its wave-rebound, though the radial artery does, and the enlarged tachographic tracings suggest either a widening of the larger arteries of the arm—or else an increased arterial dilatability due to lessened pressure.

The disappearance of the predicrotic wave is probably correlated with the suppression of some of the rebounds.

The modification in the shape of the dicrotic wave and its blending with the second predicrotic wave are probably due to some very simple variation in the mode of reflection.

In conclusion, nitrite of amyl relaxes the arterial muscular fibre ; but not evenly at all parts, nor within the same delay.

A slight administration dilates some of the shorter arteries ; this explains the deep drop observed immediately after the main summit. Meanwhile, if rather longer vessels such as the abdominal, should still give rise to rebounds, the pulse will show strong dicrotism. Should they on the contrary, like the others, become widely dilated, dicrotism is completely suppressed in the sphygmogram.

CHAPTER XI.

EPITOME OF THE FACTS AND OPINIONS CONCERNING DICROTISM.

Let us briefly review the factors which have served as a basis for the theories referred to. The following are *points of agreement* :—

(1) The direction of the dicrotic wave has been demonstrated to be centrifugal.

(2) Accurate time measurements have been made showing that :—(*a*) the wave begins at a fairly constant interval after the primary wave, and (*b*) its duration is various, being longest in the most distant arteries.

Simultaneous investigation of the dicrotic pulse in the radial artery and at the root of the aorta is still wanted as a crucial experiment, but Rolleston's endocardial studies and Roy and Adami's simultaneous myocardiagraphic and sphygmometric determinations have shed light upon some previously obscure points.

(3) The semilunar closure has also been timed and shown to precede the so-called dicrotic notch; but normally to occur after the pre-dicrotic wave (Roy and Adami's outflow-remainder wave).

(4) In the "dicrotic" pulse tracing the wave last mentioned is absent from the line of descent.

Roy and Adami conclude that it does not occur in this variety of pulse.*

(5) The systolic charge is small; or if large—and Roy and Adami admit that it may be—its size must be compensated by the ease and the rapidity of the peripheral outflow.

(6) The systole is rapid. Roy and Adami consider that it is completed at the end of the papillary contraction, leaving no "outflow remainder" to be disposed of by further contraction of the cardiac wall. This assumption of a variation in the mode of the systole must be specially noted. As to the unusual rapidity of the heart's contraction all observers are agreed.

(7) The pulse frequency is high. On this point again there is unanimity. The highest frequency gives rise to hyper-dicrotism.

Discrepancies as to important facts complicate our study of the dicrotic pulse.

(1) Arterial elasticity, viewed by Landois and almost all observers as essential to the production of dicrotism, is regarded by Roy and Adami as rather impeding than favouring it.

(2) The mean blood pressure is low according to most observers. Roy and Adami, whilst admitting that sometimes it may be low, make of such cases a separate class. For the average cases, which form

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* On the assumption that this wave is in the normal tracing an outflow remainder wave from the heart we must conclude that it has no existence in the "dicrotic" type of pulse; the rapid line of descent to the depth of the notch leaves no doubt on this score. If on the other hand we were to suppose that its production in the normal tracing were extra-cardiac, the same conclusion need not be drawn.

the majority, they hold that the arterial tension must be high, arguing that it is only a relatively rigid tube that can be the seat of oscillations of inertia, elasticity being their destruction.*

Lastly, whilst one theory looks to the heart for the cause, and, to modifications in its mode of contraction, for the variations in dicrotism ; the other relegates to the periphery both the main cause and the modifying influences, and seeks to explain every peculiarity of the pulse by means of a single heart-wave and of the various combinations of its multiple rebounds.

CONCLUDING REMARKS ON PERIPHERAL RESISTANCE AND CAPILLARY PULSATION.

Peripheral resistance has been mentioned, but not in any prominent manner ; yet it seems to be of primary importance. Any increase in the peripheral resistance must mean longer duration of the arterial pressure. Unusually short duration of the latter must imply (if the systolic charge was ample) unusual ease of outflow. How can this be brought about ? By relaxation of the arterioles first, and in the second place, by relaxation of the capillaries. Of the latter it may be said that although their dilatation must be partly passive, it is also to a certain extent active.

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* From a clinical standpoint, however great a *systolic pressure* may be recorded in different cases, experience shows that this pressure is most fugitive, and that—in the pulse—tension is decidedly not sustained. Indeed this is shown by the sphygmogram of each pulse-wave.

Increase of capillary pulsation is nothing more than might be expected. It is very marked in cases of extreme dicrotism.

Dicrotism is apparently not merely a question of rapidity of pulse rate, since a rapid pulse may preserve its normal configuration. Some modification has occurred in the time-relation of the primary and of the dicrotic beat ; and the effects of this disturbance become more conspicuous with any further rise in frequency. Thus the dicrotic rise is more and more closely followed up by the next primary ascent, ultimately becoming a mere elevation in the latter. If the rapidity should grow beyond this, whatever there may exist of dicrotism is merged into the following beat : *dicrotism becomes latent.* Under these circumstances each successive beat may be regarded as containing the dicrotic rebound of the preceding one. This type is known as the monocrotous pulse ; the pulse of intermediate type being termed hyperdicrotous.

CHAPTER XII.

THE CARDIAC MECHANISMS AND PRESSURES: THEIR INSTRUMENTAL STUDY.

The heart being the cause of the pulse and also of many of its variations, it would be impossible to do justice to the problems presented by the arterial pulse without a preliminary consideration of its cardiac factors, viz., cardiac contraction and intra-cardiac pressure.

The more recent authors have dealt with the latter, and Roy and Adami have accentuated the relationship between the cardiac and the arterial pulsation, by naming after a cardiac event one of the secondary pulse-waves.

A review of the facts and of the opinions set forth by them, and of the yet more recent work of von Frey, will best enable us to follow the diverging views taken of the pulse; and to draw our own conclusions from the analytical pulse observations described in Part III.

A consideration of the velocities of the blood and of its pressures, such as they originate in the heart, forms part of sphygmology; and the mechanism by which they are brought about bears a close relation to the pulse. Our remarks will therefore be arranged under two headings: the cardiac movements; and the intra-cardiac pressures.

THE MOVEMENTS OF THE HEART.

(*a*) *The Passive Movements.*

Some of the movements of the heart are merely passive. The varying mobility of individual hearts by gravitation, under the influence of posture, is of practical interest in relation to cardiography, and possesses also a clinical aspect which need not be dwelt upon in these pages.

(*b*) *The Active Movements.*

The active movements of the heart arising from its own contractions bring about twofold results:

I Alterations in the heart's position as a whole, and in the relations of its component parts.

II Alterations in the size of the heart's cavities.

With the first of these cardiography is directly concerned; their more distant bearing on the pulse is not yet fully understood. It is the rhythmic alternations, during each cardiac cycle, in the size, position, and mutual relations in space, of the auricles and of the ventricles which specially need to be borne in mind in connection with a study of the intra-cardiac events.

The alterations in the size of the heart's cavities.

In recent years advances have been made beyond the elementary knowledge of a systole which empties the cavity, and of a diastole during which it fills. It has been shown that the systole does not quite empty the ventricle, and that the diastole exerts a definite suctional force. The mechanism of the systole has been studied by Roy and Adami among other observers; but it cannot be said that the mechanism of the diastolic expansion of the heart has been thoroughly explained.

The Cardiac Cycle.

The Auricle.

By Roy and Adami[*] the *auricular outflow* is considered at four periods :

(I) during ventricular systole it is *nil*. (II) at the opening of the mitral it is rapid, owing to the resilience of the ventricle and to the pressure of any blood accumulated within the auricle. (III) As the ventricular expansion progresses, the ventricular resilience and the flow diminish. (IV) The contraction of the pulmonary veins and of the auricle produces increased rapidity of flow.

The Ventricle.

Roy and Adami divide the ventricular systole into five more or less distinct phases :

"Systolic Phase I : The ventricle wall is con tracting, but the musculi papillares muscles are at rest.

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[*] *The Practitioner*, vol. xliv. p. 170.

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"Systolic Phase II: The papillary muscles carry out the first rapid part of their contraction, accompanied by slowing, arrest, or retrogression of the shortening of the fibres of the heart-wall, which is most marked in tracings taken along a line running round the heart transversely.

"Systolic Phase III: The shortening of the papillary muscle is considerably less rapid than during the last phase: the fibres of the heart-wall are also being shortened, although much more slowly than during the first part of its systole.

"Systolic Phase IV: Both the papillary muscles and those of the ventricular wall remain contracted, but do not undergo further shortening.

"Systolic Phase V: The papillary muscle expands rapidly, while the ventricle wall remains contracted.

"This last phase belongs both to systole and diastole, the diastolic expansion beginning in the papillary muscles."

. . . . . .

"The duration of the contraction of the papillary muscles may be about half the duration of that of the wall of the ventricle, although the difference in duration of the two is usually less than this—the relation being about 5 to 8; the relation at all events is not a constant one."

Roy and Adami* recognise not only an independent contraction, but even a certain independence in the rhythm of the papillary and of the heart-wall muscles, as opposed to each other. Thus the force of contraction of the musculi papillares may be independently increased by *Strophanthus hispidus*—and for this reason the drug might be regarded as valuable in functional incompetence of the mitral or tricuspid valve, rather than in mitral stenosis with rigidity and with atrophy of papillary muscles. Toxic doses would likewise weaken the musculi papillares much more than the heart-wall muscles; and under their influence the papillary muscles may cease contracting, whilst the heart-wall continues to act—this cessation being sometimes preceded by inco-ordination between the two sets of muscular contractions; the papillary contraction being absent at one time, reduplicated at another.

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* *Loc. cit.*, p. 354.

The same arrest has also resulted from temporary cessation of artificial respiration.

Probably similar irregularities occur in the course of disease.

The diastole of the heart-wall may be divided into three phases, namely:—

"Diastolic Phase I: Expansion takes place rapidly, and with uniform rapidity."

"Diastolic Phase II is only well shown on the curves when the amount of blood available to permit the ventricle to expand is not great, so that the expansion becomes slowed or even arrested after the first elastic expansion of the ventricles has drawn into them the greater part of the available blood."

"Diastolic Phase III: The wave of blood which results from the contraction of the veins and auricles reaches the ventricular cavity, and causes or allows the final expansion of the ventricular wall which precedes systole . . . . The relative duration of these eight phases is not by any means a fixed one."

Von Frey* divides the *ventricular* cycle into four stages: I, during the first stage, ventricular pressure is lower than the auricular; II, in the second, the ventricular pressure is higher than the aortic; III and IV, during the two remaining stages both orifices of the ventricle are closed, and its pressure is intermediate between those of the auricle and of the aorta.

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* *Loc. cit.*, p. 90.

The following names are applied to the stages described: Spannungszeit; Austreibungszeit; Erschlaffungszeit; and Füllungszeit.

Von Frey[*] admits that the period of cardiac contraction or excitement lasts longer than the interval between the two heart sounds; yet it is not desirable to use the term systole in that extended sense, as Martius has done. In muscular contraction von Helmholtz[†] distinguishes two phases, one of waxing and one of waning energy, which Fick[‡] describes under the names of *isotonic* contraction and of *isometric* contraction. The term isotonic refers to the circumstance that the relation between the muscle and the load is such that the muscle will shorten without any alteration in its tension; whereas the isometric contraction causes a change in tension without any shortening.

The same distinctions may be traced in the cardiac contraction:

I The period during which both valves are closed is one of growing energy, or of isometric contraction.

II During the ventricular discharge, the contraction reaches its maximum.

III The interval between the closure of the sigmoid valve and the opening of the mitral is a period of waning energy—or of isotonic contraction.

During the first of these phases the fibre does not undergo shortening;

During the second phase, the fibre shortens to a minimum length;

During the third the fibre maintains this minimum length until the auricle opens.

Granted these different acceptions of the word, Landois is correct in stating that the cardiac contraction ceases before the aortic closure, and Baxt and Moens may with equal right contend that the ventricle remains contracted even after that moment.

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[*] *Loc. cit.*, p. 120.

[†] *Gesamm. Abhandl.*, bd. ii. p. 766.

[‡] "Mechanische Arbeit und Wärme Entwickelung," Leipzig, 1882, p. 112.

THE INSTRUMENTAL STUDY OF THE HEART'S MOVEMENTS.

The Myocardiograph.

Hesse's* idea of harpooning different spots of the heart's surface with a view to studying any variations in their relations, passed unnoticed, until Roy and Adami, conceiving the same idea, elaborated it into a most ingenious graphic method. The object of the instrument consists in transmitting to a revolving surface a record of the movements of two levers connected respectively with the fringe of the mitral valve (by means of a hook), and with two separate spots of the heart's external surface. For a description of the apparatus and of its mode of use the reader must be referred to the original paper.†

The Cardiograph.

According to Roy and Adami,‡ even when taken with Von Basch's instrument, the cardiographic tracing is not easily interpreted. Variations in the size of the heart, in the kind, amount, and condition of its coverings and of the underlying parts, and in the extent to which it is wedged in between the diaphragm and thoracic wall, all contribute to throw doubt upon any inferences. It is difficult, and in most cases impossible, to measure with accuracy with the cardiograph the duration of the different phases of the cardiac cycle.

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* "Beiträge zur Mechanik der Herzbewegung," *His & Braune's Archiv.*, 1880.

† *The Practitioner*, vol. xliv. 1890, p. 82.

‡ *Loc. cit.*, p. 171.

Nevertheless some data of value may be obtained, especially by combining, in animals, the determinations of the intra-ventricular pressure, and of the heart-wall contractions, with those of any change occurring in the antero-posterior diameter of the heart. With this view, the pericardium of a dog or of a cat is incised in front, and its two flaps stretched back, so as to expose the heart through a window in the chest wall, and to give it a steady and firm support from behind and from below. In this way the button will indicate with some accuracy variations of the antero-posterior diameter. A spring must be used in order to distinguish the passive increase of this diameter in the flaccid state of the ventricle during diastole, from that which may be termed the active increase during systole. "In systole, with the contraction of the ventricles, the walls become tense and resisting, the organ becomes rounded, the transverse diameter is diminished, the antero-posterior diameter is increased."

Comparing a tracing taken in that way from the left ventricle in a cat with the tracing recorded by François Franck from a case of ectopia, Roy and Adami found in both a rounded wave followed by a rapid ascent to a notched summit which passes, by a more or less rounded shoulder, into the steep descending limb of the curve. It may be safely assumed that this description also applies to the apex beat of man.

The shape of the tracing depends on the point selected, and on the degree of pressure exerted by the lever, "an endless variety of curves" being thus obtainable in any one heart. The general configuration of curves obtained with the application of weak, of moderate, and of strong pressures is at first sight very different. Roy and Adami show how these differences may be explained in connection with the suppression of the feeble forces of auricular distension and contraction, and of the ventricular suctional filling, by the superior pressure of a strong spring; whilst the main events of the ventricular systole and diastole remain undiminished in the tracing in spite of the pressure employed.

On analysis, the summit of the curve is found not to be synchronous with that of the intra-ventricular pressure. The maximum pressure corresponds with the notch in the apex tracing, both in man and in animals. And the notch corresponds with the rapid contraction of the papillary muscles.

The maximum antero-posterior diameter is of course reached before the blood leaves the ventricles.*

In tracings taken with weak pressures, the rise and the shoulder observed after the line which marks the end of systole is due to the remaining firmness of wall (resistance to distortion) and to the inflow of blood.

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* Roy and Adami remark that with a conical heart the musculi papillares act much more efficiently than they could have done with a spherical heart, although a globular cavity would be a more perfect machine as regards output.

CHAPTER XIII.

VON FREY'S CRITICISM OF THE CARDIOGRAPHIC METHOD.

The difficulties inherent to the investigation of the cardiac movements are complicated by others special to the instrument. Transmission of movement by air, well suited for the registration of small forces, is almost too delicate a method for the powerful cardiac movements. The large tracings sometimes depicted are apt to be faulty. As in the sphygmogram, very large oscillations are open to suspicion, and are in general to be avoided.

Von Frey's heart-lever (Herzhebel) is proposed as a substitute for the cardiograph. Its accuracy [*] is great in proportion to the simplicity of its construction. It consists of two equal levers coupled at an angle which is capable of being varied. One of the levers rests on the heart, the other traces the record.

A great advantage of the heart-lever is the fact that, at every stage, it bears with the same weight on the heart, and that this weight is a light one.

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[*] *Cf.* von Frey, *loc. cit.*, p. 106. The contraction of the gastrocnemius of a frog, used as a test for the two instruments, gives rise to two very different curves ; in the cardiographic curve the oscillations alleged to be artificial are of very large size.

Variability of the Tracings.

It is well known that a tracing may be greatly altered by pressure on the heart (*e.g.*, against the spinal column); and that retractile systolic impulses (such as that of the left side of the left ventricle) may be transformed in the tracing into positive oscillations, by using sufficiently heavy a pressure. Leaving aside these experimental errors, there is a *wide range of normal variations* in the movements of the heart's surface:

(1) Each spot has its own movements, differing from others;

(2) Each spot will suffer alteration in its normal or average movements according to the heart rate, and to the volume of the cardiac contents.

Von Frey draws special attention to the variability of the apex-beat, concerning which so little is yet known.

"The heart beat is the result of the systolic striving of the ventricle towards a definite shape, and towards a given relation to the great vessels. Their mobility being feeble, and that of the apex considerable, the latter rises from its position of collapse, which is entirely determined by gravitation, and traces the sharp upstroke of the curve. At this level the apex is maintained during the whole period of excitation, because the emptying of the heart does not lead to shortening of the axis, but only of the transverse diameters of the heart. Nevertheless, a small degree of shifting may be caused by movements of translation of the whole heart, or by tension and stretching of the great vessels. On the whole, however, the apex-tracing is a curve of excitation (erregungs curve). The curve much exceeds in length the period of output, because the cardiac muscle needs time to raise the intra-ventricular pressure to the level of the aortic pressure, and to allow it to return from the latter to the pressure of the atmosphere. Between the apex-beat and the course of the intra-ventricular and intra-aortic pressures there exists no fixed and rigid relation. The details of the cardiogram do not therefore avail to explain those of the pulse-curve; on the contrary, they themselves most need explanation.

The Limitations of the Cardiograph. It does not Indicate the Moments of Aortic Closure, nor of Aortic Opening.

Neither of the aortic events being sharply defined in the cardiographic tracing, von Frey* points out that the heart-beat is incompetent to give precise information concerning the changes in cardiac volume and pressure.

The cardiogram (which begins exactly with the first sound), presenting invariably in animals a longer period of cardiac activity and a shorter period of cardiac rest, whilst the systole (reckoned in the sense of Donders and Volkmann † as the interval between the first and the second sound), is shorter than the diastole, the second heart-sound, of *aortic closure*, must obviously strike before the end of the tracing.

This may be proved by means of a simultaneous endocardial pressure curve, aortic closure following very soon after the moment of maximum endocardial pressure.

In the cardiogram, by unanimous consent (except Edgren's),‡ this point occurs in the line of descent—or else in the "plateau"—according to the cardiac site selected for the observation.

Again, the opening of the aortic valves is not clearly indicated in the cardiogram. This can be proved by comparing simultaneous tracings of the heart's apex-beat, and of the pulse of the carotid (the latter curve being taken by means of Marey's tambour). In this way, von Frey and Krehl (in opposition to F. Martius'§ contention that the apex-beat coincides with the opening of the aortic valves), were able to demonstrate that the carotid pulse invariably begins before the lever of the cardiograph has reached the full height of its ascent. (See Fig. 116, p. 278.)

In the light of these facts, Fr. Franck's "Cardiographie Volumétrique" is clearly based on a wrong principle, and cannot be correct, even when applied to auricular tracings. The endeavour to demonstrate a general agreement between the cardiogram and the endocardial pressure curve, especially as regards Marey's "Plateau Systolique" and its undulations, is likewise futile. Neither does von Frey see any hope in Edgren's attempt to determine, from a study of coinciding maxima or minima of the pulse and heart tracings, the velocity and the direction of pulse-waves.

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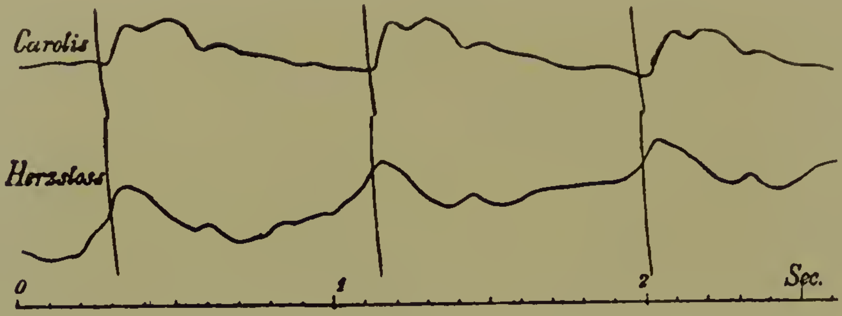
* *Loc. cit.*, p. 118.

† Volkmann, A. W., "Haemodynamik nach Versuchen," Leipzig, 1850, p. 358 *et seq.* "Donders Nederl. Archiv. Voor Genees-en Naturk," bd. ii. 1865.

‡ "Skand. Arch. für Phys.," bd. i. 1889, s. 67.

§ Martius, F. (*Zeitsch. f. Klin. Med.*), bd. xiii. 1888.

FIG. 116.



Simultaneous tracings from the carotid and from the apex-beat of a healthy man (v. Frey, *loc. cit.*, p. 117).

THE AORTIC PULSE TRACING.

The tracing of the pulsation of the innominate (which for practical purposes may be regarded as equivalent to that of the aorta) has over the radial tracing the advantage of simplicity, and is readily compared with that of the left ventricle.

During the systolic or shorter portion of the wave hardly any difference, except one of altitude, is noticeable between the ventricular and the innominate tracings, but during the diastolic portion the tracings are entirely different. In the ventricle the pressure falls to zero and hardly rises above that level until the ensuing systole. In the aorta there is no sudden drop, but a gradual subsidence, the oblique line of which is wavy. This difference is expressed very clearly in the diagram (von Kries).

FIG. 117.

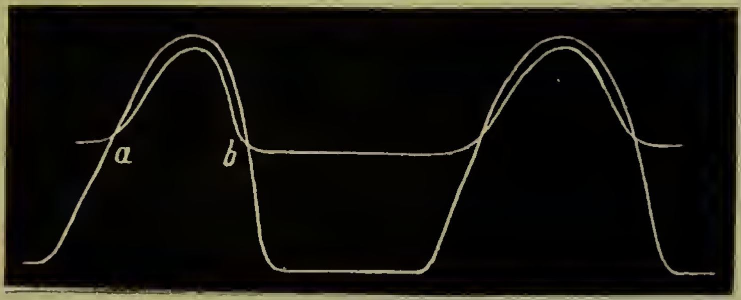


Diagram of the relative behaviour of the intra-ventricular, and of the intra-aortic pressure, in the absence of rebound-waves and of regurgitation. (v. Kries, *loc. cit.*, p 73).

The intra-ventricular curve of pressure rises before the aortic curve—in other words, before the opening of the aortic valves, which cannot be raised until the pressure below them surpasses that from above. From that moment the aortic curve shares in the rise; and since it attains its maximum almost at the same instant as the intra-ventricular tracing, its ascent is rather more abrupt than that of the latter, as well as shorter.

In their fall the two tracings are for a time identical, the two cavities being still continuous. But as soon as the first muscular relaxation occurs in the ventricle,* occasioning a rapid fall of intra-ventricular pressure, the sigmoid valves complete their closure. The ventricular pressure continues to fall rapidly, and at last becomes suctional: on the contrary, the aortic pressure continues to fall only for a moment, this fall probably not exceeding the loss of pressure represented by the peripheral outflow and by the distension of the sinuses of Valsalva. Next follows a secondary rise.

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* According to Roy and Adami, the relaxation of the musculi papillares.

Von Frey draws attention to the fact that the valve closure may occur at varying intervals after the maximum pressure has been reached.

The diastolic portion of the aortic curve is marked by secondary oscillations of pressure (which, as pointed out by von Frey, never outstep the limits of one pulsation). The first of these has given rise to much speculation. It would be hardly profitable to enter, at this place, into a discussion of the various theories which have been advanced * for its explanation.

The Oscillations of Velocity at the Root of the Aorta.

Concerning the positive oscillation, or rise, of the *velocity*, we know nothing. This is a difficult problem still in a backward state. Probably, like the endocardial pressure, the curve of velocity has a sharp summit. Von Frey inclines to imagine it may rise less rapidly than it falls. Evidence on that point is wanting.

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* Von Frey who believes this secondary elevation to be a reflected systolic wave, as no influence capable of giving rise to it can be traced in the heart or in the aorta, has strong arguments against its nature as a "valve-closure wave." He ventures so far as to say that it may sometimes arise before, although it usually arises after, the closure of the sigmoid valves; but admits that he possesses no strict experimental evidence in support of this opinion.

Owing to the influence of friction* the pressure and the velocity at the root of the aorta *cannot be exactly parallel.*

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* Von Frey (*loc. cit.*, p. 179–180) attributes to friction the fact that sigmoid closure always occurs at a higher pressure than sigmoid opening, and that the pressure continues to fall, down to the next systole.

CHAPTER XIV.

THE INTRA-CARDIAL PRESSURES.

The Intra-Auricular Pressure.

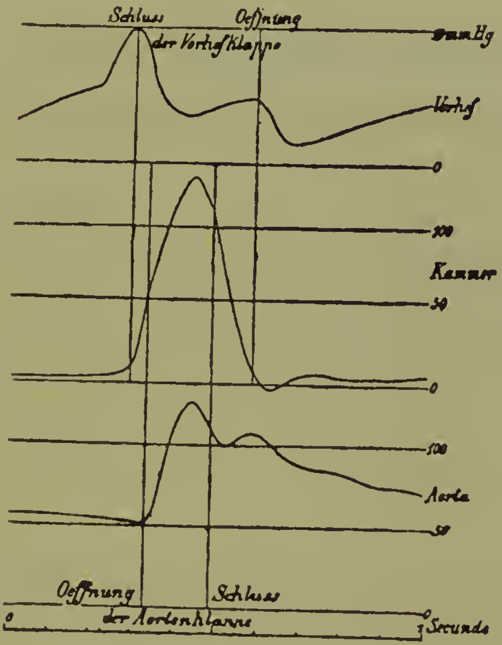
THE auricular curve, according to von Frey, rises rapidly up to the moment of the closure of its valves. Then, after a very brief delay, it yet more rapidly sinks to a low level, from which it slowly rises to a much lower secondary elevation. The blunt summit of the latter coincides with the opening of the auriculo-ventricular valves. The deepest level between these two rises exactly corresponds with the moment of maximum intra-ventricular pressure (see Fig. 118).

With the opening of the valves the blood is discharged into the ventricles, and the auricular pressure suffers a second fall to a still lower level. This fall, though shorter, is less rapid than the fall observed after the auricular contraction. The ensuing trough is also short, and is followed by a gradual and steady rise of auricular pressure, whilst the ventricular pressure remains low and keeps level as far as the foot of the systolic upheaval.

Although there are two elevations in the curve, there is but one auricular contraction. According to von Frey, the secondary elevation is due to the fact that the shrinking of the ventricles within the thoracic cavity tends to expand the auricles.*

Something more direct than this passive thoracic suction may take place. The writer is inclined to view the broad trough as partly due to an active dilatation of the auricular cavity by the papillary contraction.

FIG. 118.



Pressure curves of the auricle (Vorhof), of the ventricle (Kammer), and of the aorta, showing the time of opening and of closing of the ventricular, and of the aortic valves (v. Frey, *loc. cit.*, p. 88).

An analysis of von Frey's tracing,† discloses the following variations of pressure:

At its lowest level, the auricular pressure appears to be about 2 mm. of mercury, corresponding to the moment when the ventricular pressure, after being negative, rises to about 5 mm.—a level which it preserves till the auricle contracts. It then attains to 10 mm. at the moment of closure of the auriculo-ventricular valves.

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* ". . . . so lange der Thorax uneröffnet ist, die Verkleinerung der Herzkammern auf die Vorhöfe enfaltend wirkt" (*loc. cit.*, p. 90).

† Fig. 28, *loc. cit.*, p. 88.

From this lowest level of 2 mm. the auricular pressure steadily rises and, just prior to its own systole, it has risen so as to be at least equal to that within the ventricle. Then follows the systole of the auricular appendages which affords material for the auricle to contract upon, and enables the pressure to rise 10 mm., both in the auricles and in the ventricles.*

The Intra-Ventricular Pressure Curve as Interpreted by Roy and Adami.

Roy and Adami (*loc. cit.*, p. 165) state that no appreciable rise in the ventricular curve usually occurs from auricular contraction. This circumstance they explain by the absence of valves from the auricular orifices of the large veins, and by the ready yielding of the ventricular walls during the diastolic influx.

When present the first slow rise may be attributed to an "elastic stretching (previous to contraction) of the musculi papillares."

In the composite intra-ventricular curve the two component waves do not bear a constant relation to one another. The superposed wave may rise high or hardly above the main upper level. It is not due to inertia-vibrations, which are obviated by piston friction. It corresponds in time to the interruption which the myocardiograph indicates as occurring in the ventricular wall contraction, and which is obviously due to the pulling down of the flaps of the auriculo-ventricular valves, and to the resulting increased resistance to, and delay of, the heart-wall contraction.

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* N.B.—During this period the auricular systole takes effect on the ventricular walls and also on the mitral valve and on the aortic valve. During the next stage the ventricular systolic pressure is opposed by the ventricular wall and by both valves.

The fall which follows upon the superposed wave represents outflow into the aorta. The same cause explains in other figures the slowing of the rise before the maximum is reached.

The papillary wall contraction continues, although slowly, till the point is approached where cessation of ventricular wall shortening is indicated by the myocardiographic curve. The slightly earlier cessation of papillary contraction is sometimes marked by a notch in the pressure curve, or the latter may simply present a peculiar roundness instead of a sharp drop.

The Variations in Arterial Blood-Pressure and their Effects on the Heart and Arteries.

The Effects of a Rise of Blood-Pressure on the Cavity, on the Contraction, and on the Internal Pressure of the Ventricle.

In speaking of the variability of arterial blood-pressure, Roy and Adami* estimate that the latter "may rise as high as 250 mm. of mercury, or more, and may fall as low as 50 mm. without death or syncope from cerebral anæmia taking place."

Normally, it is capable of varying much, and is subject to constantly recurring oscillations such as those due to respiration, muscular exertion, and many others.

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* *Loc. cit.*, p. 253.

I *Effects on the Ventricular Cavity.*—A rise in the systemic arterial pressure would, according to Roy and Adami* diminish the shortening of the heart fibres, and this in turn would increase the residual quantity of blood left in the ventricle after systole.† Meanwhile, there is no decrease in the output, because diastole brings with it an increased expansion. Thus, "a physiological dilatation of the ventricles" would be the result of a rise in the arterial blood pressure. This would differ only in degree from pathological dilatation, and might, like the latter, be complicated with functional incompetence of the auriculo-ventricular valves. Hypertrophy of the wall would also result.

Roy and Adami‡ infer a diminished bulging upwards of the auriculo-ventricular valves in the physiological dilatation, owing to the increased distance, for which correction could not have been provided, between the foot of the papillary muscles and the base of the heart. This defect, together with the weakened condition of the wall from which the papillary muscles spring, would render papillary contraction less effective.

II *Effects on the Ventricular Contraction.*—The opening of the sigmoid valves is delayed. The papillary contraction, not being delayed, fails during its first part to effect any output, and "leaves a larger proportion to be expelled by the continued contraction of the heart-wall, after the auriculo-ventricular valves have been pulled down by the first rapid effective part of the contraction of the papillary muscles."§

III *Effects on the Intra-Ventricular Pressure-Curve.*—The pressure-curve becomes anacrotic—*i.e.*, the height of the superposed papillary wave is lessened, and may fall short of the level of the shoulder which follows—and a notch may precede the latter: this modification of the curve is not in itself an abnormality.

The Effects of a Rise of Blood-Pressure on the Arteries.

I On the artery itself the effect of a rise in ventricular pressure is to raise the pressure towards the end of systole, by increasing the rigidity of the arterial wall. Prof. Roy (*Jour. of Physiology*, vol. ii.) has shown that, with increasing pressures, above the normal blood-pressure of any animal, the arteries become more and more rigid.

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* *Loc. cit.*, vol. lxiv. p. 347.

† Roy and Adami, *Brit. Med. Jour.*, Dec. 15, 1888.

‡ *Loc. cit.*, p. 351.

§ *Loc. cit.*, p. 349.

An anacrotic rise in the pulse and pressure curve must result, since the output, as a rule, is not diminished but rather increased (with lessened frequency of beat) by rising pressures; and that at least the same volume of blood must be injected, with greatly increased effort.

The Effects of Low Blood-Pressures on the Ventricular Contraction.

II With low arterial pressures (which are often due to a small ventricular output) the opposite conditions obtain. The sigmoid valve opens early; the outflow is of short duration; and the papillary contraction takes a large share in the event. The pulse-wave is thus made up mainly by the superposed wave which is due to the musculi papillares.

Modifications of the heart-beat also occur under the influence of the nerves (chiefly acting on the auricles), and of a variation in the quantity of the ventricular output, which is generally smaller the more frequent is the beat.*

The Intra-Ventricular Pressure-Curve Interpreted by von Frey.

The ventricle is the seat of the highest and of the lowest pressures to be found in the arterial system. The ventricular pressure-curve obtained by von Frey is given in Fig. 118, together with those of the auricle and of the aorta (through the Innominate). A very slow heart's action was purposely selected.

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* Von Frey (*loc. cit.*, p. 200) observes in connection with the relation between heart-rate and arterial pressure, that whenever the heart-rate is increased within certain limits, arterial pressure will rise, and the Anspannungszeit is supposed to be lengthened, at least relatively: the semilunars will open late and the systole will be a short one. A lessened heart-rate would be combined with the opposite conditions.

A great difference is perceived between this curve and that of Roy and Adami. The oscillations, which they put down to papillary contraction, von Frey (*loc. cit.*, p. 85) attributes to inertia.

The auricular systolic rise in pressure is stated to occasion a faint analogous rise in the ventricular pressure. Then occurs the closure of the auriculo-ventricular valves, and both sets of valves being closed, tension is rapidly got up. The opening of the semilunars marks the beginning of the great aortic rise in pressure, to which (when the valves open early, as during vagus stimulation), corresponds a perceptible slowing of the rapidity of increase of pressure. (This is not perceptible under ordinary circumstances owing to the natural bend of the intra-ventricular curve as it approaches its summit).

The pressure rises in the ventricle with lessening steepness; and the line of its fall is almost symmetrical with that of its ascent. A slight modification may, however, indicate (high up) the closure of the aortic valves.

The fall of pressure persists, and, for a moment after the opening of the auriculo-ventricular valves, it even becomes more rapid. Thus for a brief space of time the ventricular pressure is falling as well as the auricular.

The varying duration of the entire cardiac revolution at different rates of frequency being admitted to represent variations in the duration of diastole, in very quick action of the heart, not only is the latter shortened, but a portion of the negative phase of pressure is also lost. Irregular action will sometimes give rise to double summits within the positive phase of the tracing. In some instances a second small positive oscillation has been observed to follow immediately after the negative phase; it is certainly not due to inertia. Its significance is unknown. Is it to be regarded as a proof that the ventricular muscle is still in a state of activity during the phase of negative pressure?[*]

Von Frey's serial tracings,[†] obtained at gradually lessened depths within the ventricle, have convinced him (1) that the cardiac contraction is in the nature of a peristaltis, progressing from the apex towards the base; and (2) that a complete and unadulterated ventricular pressure-curve can only be obtained when the sound is introduced immediately below the aortic flaps, into the space which the strongest systole leaves patent. The cardiac sound, if pushed beyond this space, is tightly grasped by the muscle—at an earlier or at a later instant of the systole—according to the depth of its penetration into the ventricular cavity.

The Negative Phase of Intra-Ventricular Pressure.

Roy and Adami[‡] state that "a phase of negative pressure during diastole is not of constant occurrence," nor could it be, so long as a large supply of venous blood is available.

The interruption of expansion coinciding with an intra-ventricular negative pressure occurs late (after about three-quarters of the total diastolic elongation); it might be regarded as due to the supply not keeping pace with the elastic expansion of the heart.

The inflow from the auricle at the opening of the mitral may cause a positive wave on the line of descent of pressure (*loc. cit.*, Figs. 8 and 11B).

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[*] Rolleston, H. D. (*Jour. of Physiology*, vol. viii. p. 235), suggests a somewhat different explanation.

[†] *Loc. cit.*, p. 87.

[‡] *Loc. cit.*, p. 188.

According to von Frey, the old view originally propounded by Marey was to the effect that the negative phase was due to the suctional force exerted by the elasticity of the lung. The observations of Goltz and Gaule, which revealed the existence of much greater negative values than previously suspected, rendered necessary some other form of explanation.

Two views at present prevail :

(1) That of an independent expansion of the ventricle ;

(2) That suggested by Moens under the name of Schliessungswelle (negative wave of closure), the interruption of a current being supposed to generate a negative wave starting from the seat of interruption. In the aorta, however, where it might have been expected to have been most marked, no such wave is to be traced. Moreover, it is matter of demonstration that the negative intra-ventricular phase of pressure occurs an appreciable time after aortic closure, when aortic pressure is decidedly positive (see Fig. 117).

The Mechanism of Ventricular Expansion.

Independent expansion of the ventricle might, in von Frey's opinion, be brought about in one of two ways :

(1) By elastic recoil of its walls ;

(2) By active muscular contraction of dilator fibres.

(1) In diastole an isolated empty heart is not maintained in any definite shape by its intrinsic elasticity—or rather by the elastic tissue it contains. It is flaccid, and assumes various shapes according to the amount of support it gets from below and from the sides. Even its orifices, which are more fibrous than other parts, readily undergo deformation. In systole, on the contrary, the shape and the relative position of the orifices can be strictly defined. They have been well depicted by Hesse.*

From this definite systolic shape, a spontaneous recoil is quite conceivable, and it may be observed that the elastic recoil of surrounding structures may add its effect to those of the ventricular recoil.

(2) The other possibility, although conceivable, still lacks the

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* His and Braune's Archiv., 1880, p. 328.

support of anatomical demonstration. We should have to assume dilating fibres possessing not only a different direction, but also a different time of contraction from those special to the constricting fibres.

It has been alleged, on the assumption that the coronary circulation was interrupted during systole, that the injection of the coronary arteries might assist in expanding the heart-wall. This assumption is opposed to physiological facts ascertained in connection with the circulation within skeletal muscles. A mechanism of this sort would entail serious danger to the nutrition of the heart during rapid action.

The theory of active muscular dilatation has had the support of Magendie, Spring, Luciani.*

Von Frey observes in this connection that the activity of the cardiac fibres does not begin simultaneously at all parts, but in a peristaltic wave starting usually at the base. Similarly many observations justify the view that all fibres do not cease their contraction at the same moment.

In commenting upon the observations made by Gaule† and by Mink,‡ of a dilatation of the extreme base of the ventricle by the distension of the sinuses of Valsalva, von Frey§ remarks that the aorta when empty is narrowed by the contraction of the muscular fibres which surround it, and does not acquire its full expansion until this contraction is at an end.

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* Rollett, Hermann's Handbuch IV., i. p. 180, 1872.

† Gaule, "Corresp. Blatt für Schweiz. Aerzte," xvi. 1886.

‡ Mink, "Central Blatt für Physiol.," iv. 1890, No. 21.

§ *Loc. cit.*, p. 94.

PART V.

FURTHER TACTILE STUDIES.

Some of the deductions with which this part is concerned must have already been drawn by the reader. In some instances the evidence afforded by tactile exploration as to the intra-arterial events is direct and demonstrative. In others it has simply the value of suggestion and sometimes of inference.

We propose to review seriatim the data obtained by our analysis of the tactile pulse-sensations, and to gather materials for a critical comparison between the tactile and the graphic instrumental results.

The subjects which will more specially engage our attention are:

I The Ictus or Pulse-beat, and its modifications;
II The Anastomotic wave;
III The Pulse thrill;
IV The Dicrotic wave;
V The modifications induced in the pulse by Posture.

CHAPTER I.

GENERAL NOTIONS CONCERNING THE NATURAL OR SPONTANEOUS ICTUS AND THE MODIFIED OR ARTIFICIAL ICTUS.

The Natural or Spontaneous Ictus.

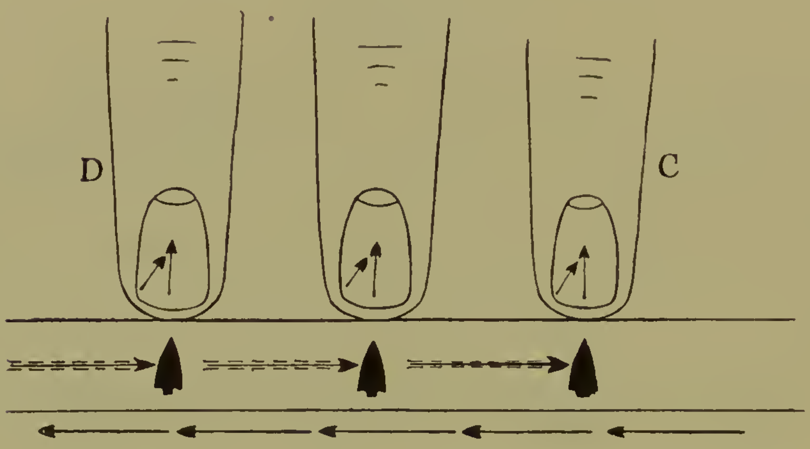
When the finger is applied to any accessible artery, as in Experiment A, Fig. 26, so lightly that no appreciable pressure on the artery or alteration in its shape is effected, any ictus then felt must be a spontaneous intra-arterial event. This is amply proved by the fact that, without applying the finger, the ictus may be seen in any artery which chances to be sufficiently superficial.

In arteries of this kind it may be seen or felt anywhere and everywhere : it is ubiquitous.

This is another strong argument in favour of its spontaneous origin, and against any suspicion that it might be due to some purely local circumstance such as the pressure of bones or of tendons, fixation by adhesions, or by arterial divisions, or intra-arterial resistances at the sharp curves of the vessel, etc.

The natural ictus, perceived at a mere point of contact, is identified by the finger as a terminal sensation, as a stroke in the direction of its long axis. This limitation is misleading, and is due mainly to the small size of the palpating surface. Far from being confined to one point, the process extends along the whole artery as a long, sometimes visibly pulsating tract. If the finger be shifted a minute distance upwards or downwards, the ictus will still be felt, and in this way it may be followed up the arm. In a word, it is *continuous, and partakes of the nature of a wave.* This, however, is all we can learn by the touch, any pressure such as is requisite for successful palpation causing changes to occur, or to be suspected.

FIG. 119.



The continuous, wave-like progression of the ictus, recognised by a finger shifted gradually from D to C.

The Ictus and the Pulse-Wave.

It is enough to remind the reader of the elementary description of the pulse-wave on p. 102, to save any confusion between the ictus and the onset of the wave. The ictus does not occur at the beginning of the pulse, as a careless palpation might suggest, but after a short delay. It is the acme of the tactile wave. Whether it also exactly corresponds with the acme of the sphygmographic tracing cannot be definitely stated; most probably it does.

The Artificial Ictus.

The natural ictus is superseded, and an artificial ictus is set up, as soon as definite pressure is made on the artery as in experiments B, C, and D. By this the character of the ictus and its position with regard to the finger are changed; the modifications being very different according to the degree of pressure used. Owing to these essential differences between the results, the general features only are capable of being compared.

The artificial ictus has no independent existence apart from the pressure which causes it; yet it exists potentially, and can be elicited, wherever there is a natural ictus. Wheresoever it is called forth it takes the place of the natural ictus, but it remains limited to the site of the application of the finger.

The Three Varieties of the Artificial Ictus.

The tactile results of varying systematically the pressure of the finger have been described in Part III. (p. 123). It will be convenient to identify each of these modifications with the localisation of the sensation experienced by the finger; and to distinguish under the following names:

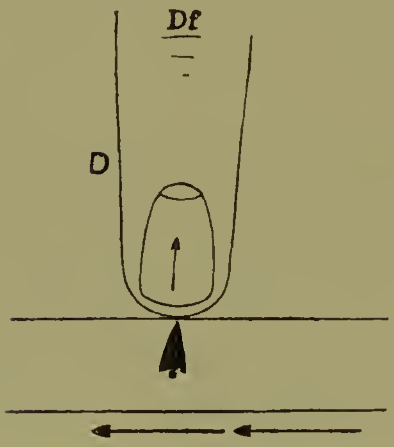
Distal ictus,
Intermediate ictus,
Proximal ictus,

the special results of pressure ii, pressure iii, and pressure iv.

The General Resemblance between the Natural and the Intermediate Ictus.

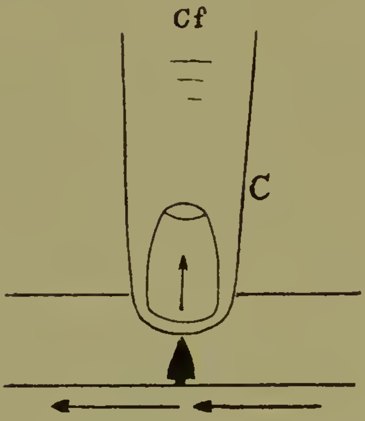
Of these three varieties the least unlike the natural ictus is the intermediate. The sensation in both cases has its seat at the extremity of the finger; and, if the pressure of light contact be increased sufficiently quickly, the terminal sensation will not suffer any displacement, but simply extend its area to the entire width of the pulp. This identity in localisation is an argument in favour of a common origin.

FIG. 120.



The natural ictus (pressure i).

FIG. 121.



The intermediate ictus (pressure iii).

With the proximal and with the distal varieties, the natural ictus has much less outward resemblance. Since, however, they are so closely connected with the intermediate ictus, as to be gradually developed from the latter by respectively increasing or decreasing the pressure, their relationship to the natural ictus is a close one also; and we are led to regard the spontaneous and the artificial forms as possessing the same derivation.

The Inquiry as to the Nature of the Ictus.

Unable to palpate satisfactorily the natural ictus, we shall find our easiest way to a knowledge of its nature in a study of the three kinds of artificial ictus, the conditions of which we are able to modify at will :—beginning with the Distal Ictus.

CHAPTER II.

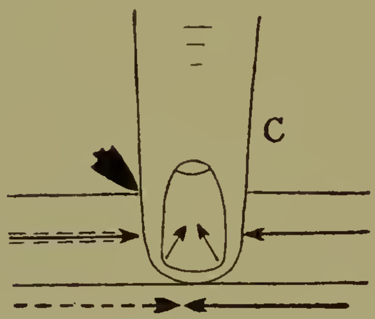
THE DISTAL ICTUS.

THE distal ictus is produced when the lightest pressure of the finger is increased to the second degree of pressure. The anastomotic pulse from the hand also strikes the finger on its distal side. We may with advantage avail ourselves of this similarity in the present study.

Experiment XXXV.

When in any subject we test for the anastomotic wave, the force used to obliterate the artery is such as to obviate any possibility of the transmission of a direct wave. The anastomotic wave at the wrist, without any doubt, is genuinely retrograde.

FIG. 122.

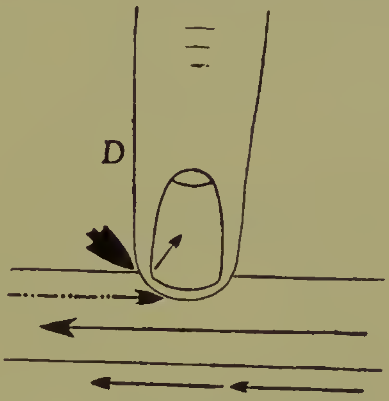


The anastomotic wave striking the finger distally (pressure v).

Let us now feel the distal ictus in another subject previously tested and found free from any anastomotic wave at the wrist.

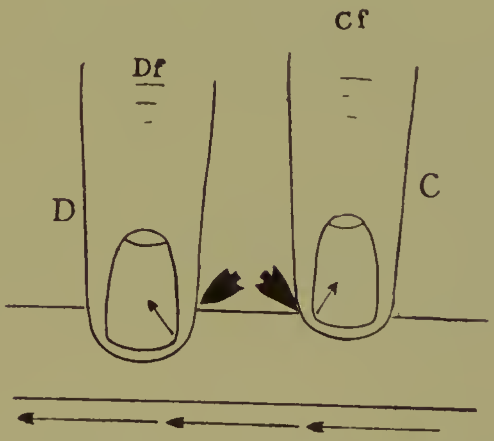
The ictus resembles so closely the anastomotic beat felt in the first, as to force upon us the conclusion that, likewise, it strikes backwards. If such be really its direction, since the pulse-wave is not transmitted round the palmar arch in the subject under examination, the beat must be due to a rebound of the direct wave, after it has passed under the finger onward to the hand.

FIG. 123.



The direct wave rebounding to the distal side of the finger —in a subject free from anastomotic pulsation (pressure ii).

FIG. 124.

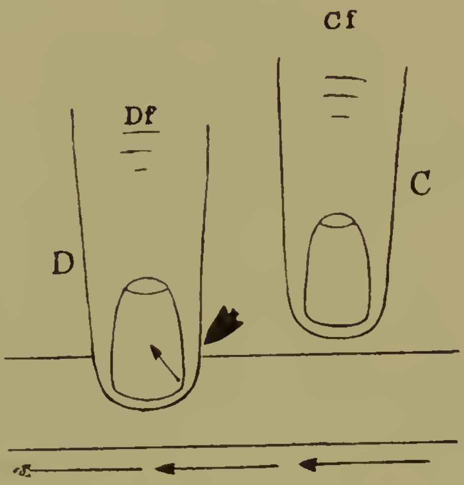


Df applied with pressure iv, *Cf* with pressure ii; two forms of ictus felt.

The best proof of the reflux nature of this ictus would be that which would also demonstrate the source of the rebound. If a finger *Df* be placed on the artery at a more peripheral point (the minimum pressure being used which shall suffice to elicit the proximal beat), it will be possible to combine a feeling of the distal ictus at *Cf*, and of the proximal ictus at *Df*.

If now the finger *Cf* be lifted, no perceptible change will occur at *Df*, except a slight alteration in the strength of the proximal ictus; and from this we may conclude that the wave producing the ictus must be travelling with the direct wave and must be identical with it.

FIG. 125.



The proximal ictus at *Df* not disturbed by raising *Cf*.

On the other hand, if, whilst *Cf* is in light contact with the pulse as before, *Df* be applied with full pressure, the same kind of distal ictus will continue to be felt at *Cf*, only with much more strength than before.*

Concerning the kind of effect produced on the systolic wave by thus obliterating the artery, there can be no question. A rebound must take place against the obstacle; and it is this rebound which must be felt by *Cf* on its distal side.

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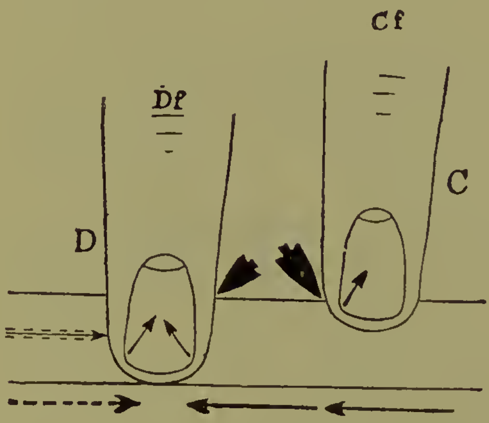
* *Cf.* Expansile Reaction of Oliver.

Since the tangible effect of interposing the obstacle *Df* is merely to increase, and the effect of removing it is merely to diminish the strength of the distal ictus at *Cf*, it may be taken as proved that the distal ictus, also in the absence of any obliteration at *Df*, is a rebound produced in the same way as when the pressure *Df* is made. "*Back-stroke*" is therefore a term applicable to it in perfect strictness.

FIG. 126.



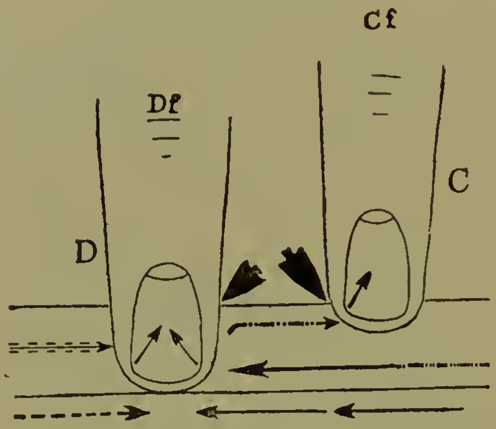
The distal ictus at *Cf* intensified by using *Df* as block. Its mode of production by rebound.

The site of the reflection may be at any part of the interval between the finger and the peripheral venules. Most probably, as argued by von Frey and others, the rebound occurs at the entrance of the capillary district.

The Mechanism of the Distal Ictus.

The mode of production of the distal ictus or back-stroke must now be tolerably obvious. On its passage up the arm, the reflected wave strikes against the distal side of the finger (in this case *Cf*), which feels the blow. Had *Cf* been placed at any other spot over the radial artery, the same wave would have struck it.

FIG. 127.



The direct wave, intercepted by *Df*, becomes a reflected wave, and strikes the distal side of *Cf*.

Two conditions are necessary on the part of the finger *Cf*:

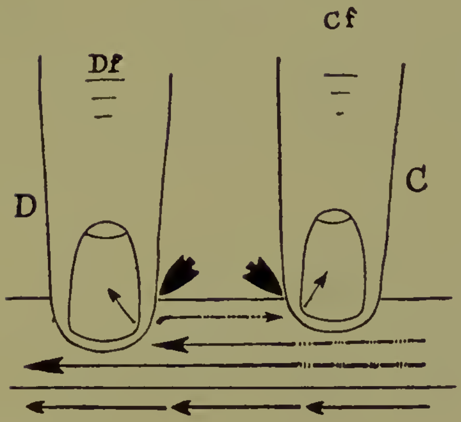
(1) That it should project sufficiently into the lumen of the artery to fairly catch the rebound;

(2) That it should not project so deeply into it, as to prevent or greatly impede the passage of the direct wave.

Pressure ii (p. 97) is exactly of a kind to secure these conditions.

The reason is now apparent for the preference given to the term "anastomotic" over that of "reflux wave." A backward wave occurring much more often as a result of rebound, than by way of anastomosis, it was thought necessary to avoid any verbal confusion in connection with these two retrograde waves.

FIG. 128



Cf, applied with pressure ii, allows the direct wave sufficiently free passage to secure recoil at the periphery, (or, as here shown, against *Df*), and a distal ictus.

Confirmatory Proofs of the Rebound.

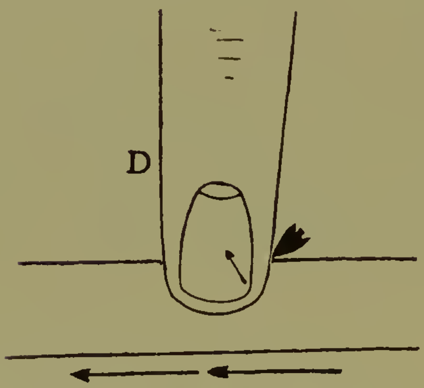
Confirmatory proofs of the direction of the distal ictus are supplied by a study of the anastomotic wave itself; this more complicated inquiry we must for the present defer (see p. 333). The most conclusive of all proofs is that to be obtained from a determination of the relative time of the ictus; but we shall postpone the discussion of the time-proofs until we have dealt with the general features of the proximal ictus.

CHAPTER III.

THE PROXIMAL ICTUS.

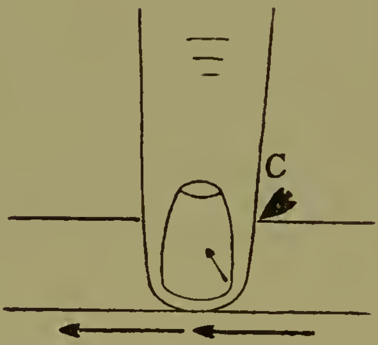
The proximal ictus, which strikes the central side of the finger, is obtained with pressures iv and v (see p. 98), the localisation remaining the same under both degrees of pressure—that is, when obliteration of the artery by the finger *Cf* is partial only, as well as when complete. It would be rash to assert that, with the lighter of these two pressures, no part of the direct systolic-wave can find its way under the finger to the hand. The description of the tactile

Fig. 129.



The proximal ictus with pressure iv. (The finger should have been shown sunk rather more deeply in the artery.)

Fig. 130.



The proximal ictus with pressure v.

sensations given on p. 120 implied that the wave is stopped by pressure iv, and so far as the finger can judge it generally is. We shall confine ourselves to a consideration of the case of absolute obliteration as being the simpler one.

The Phase of the Pulse-Wave Corresponding to the Proximal Ictus.

The mechanism of the proximal ictus is not as simple as it might appear at first sight. We might be tempted to regard the stroke as marking the arrival of the systolic heart-wave. The latter is a distinct event, which can be perceived by the finger in favourable subjects, but which does not possess the importance of an ictus. At the periphery the onset of the systolic wave is a stage of rapidly growing, but at first of slight pressure only; and, so long as the increase of pressure is smooth and steady, it is difficult to see why an ictus should arise. We look for some interfering influence proportionately abrupt.

FIG. 131.

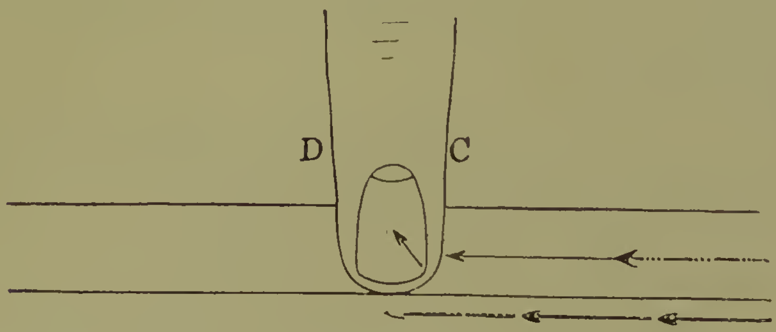


Diagram of the ictus (interrupted arrow) following the onset and growth of the systolic-wave (finer arrow).

According to the old view which admitted a " percussion-wave," or according to the view of Roy and Adami, who describe a "papillary-wave," the abrupt event is connected with the systolic heart-wave itself —and, we may infer, with some mechanical peculiarity of the heart's action ; for normally waves rise with a smooth ascent to their acme. A discussion of these important theories cannot be attempted at this stage.

The Rebound-Wave in Relation to the Proximal Ictus.

Meanwhile, without going beyond the wave-theory, it is possible to apply to the explanation of the proximal ictus the same reasoning as that which was used for the distal. The back-stroke from the hand could not, in this instance, ascend the radial artery, which is obstructed; but it might be conveyed by the ulnar artery to the point of bifurcation of the brachial. The hand would not be the only district contributing a rebound ; the arteries of the arm might furnish their share.

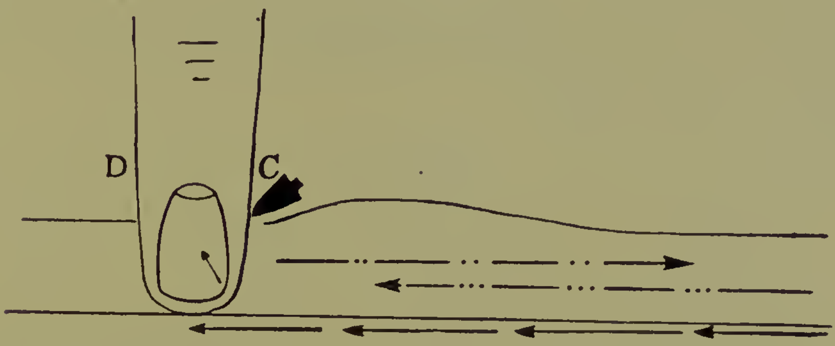
From all these sources the back-stroke would travel not only in an ascending, but in a downward and centrifugal direction also, belying its name.

In the radial artery it would be a descending wave, adding itself to the direct systolic wave, and reinforcing the volume and the pressure of the latter.

The impact of this compound wave against the finger would inevitably produce a shock—where the thin end of the systolic wave had produced none.

At the same time the descending rebound would encounter the ascending rebound due to the impact of the early portion of the direct wave against the obliterating finger. This collision between opposed reflux waves might in itself be competent to occasion the ictus.

FIG. 132.



The *descending rebound* (arrow with three dots), derived from districts higher up in the arm ; and the *ascending rebound* (arrow with two dots), occasioned by the block. The systolic wave is not shown. The artery is distended by the added pressures of the wave and of the rebounds.

Conclusions.

The following conclusions appear to be warrantable :

(1) The proximal ictus is not due to the shock of the onset of the systolic heart-wave.

(2) As a preliminary sensation preceding the ictus we should expect the finger to perceive first the onset and then the gradual rise of the systolic wave.

(3) The ictus may be due to the sudden expansion of the systolic wave by the accession of the descending wave of the rebound.

(4) It may also be due to the conflict or conjunction of the descending wave of rebound with the rebound from the finger compressing the artery, or ascending rebound-wave.

(5) The size of the ictus, that is—of the artery at that moment—would be considerable, since three waves (all three of positive pressure) would be contained within the vessel, viz.:

(*a*) The direct systolic heart-wave, (*b*) its ascending rebound-wave, and (*c*) its descending or collateral rebound-wave, arising in the ulnar artery and in other arteries of the arm.

FIG. 133.

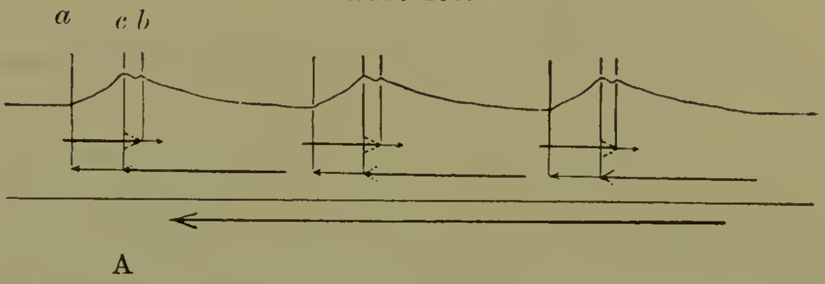


Diagram of the three waves of positive pressure in their relation to the ictus: (*a*) the systolic-wave, (*b*) its rebound from the hand, (*c*) its rebound from the arm above.

N.B.—The arrows represent the relative time of the events, reckoned from A.

(6) Owing to this composite character, and to the slight want of synchronism of the various rebounds, the proximal ictus would be slightly less abrupt, and its duration slightly increased.

The conspicuous size of the pulsation observed a little above the seat of obliteration has already been dwelt upon (see pp. 158). It has also attracted the notice of other observers, in particular of Marey and of Dr. G. Oliver.

CHAPTER IV.

THE RELATIONS IN TIME OF THE PROXIMAL AND OF THE DISTAL ICTUS.

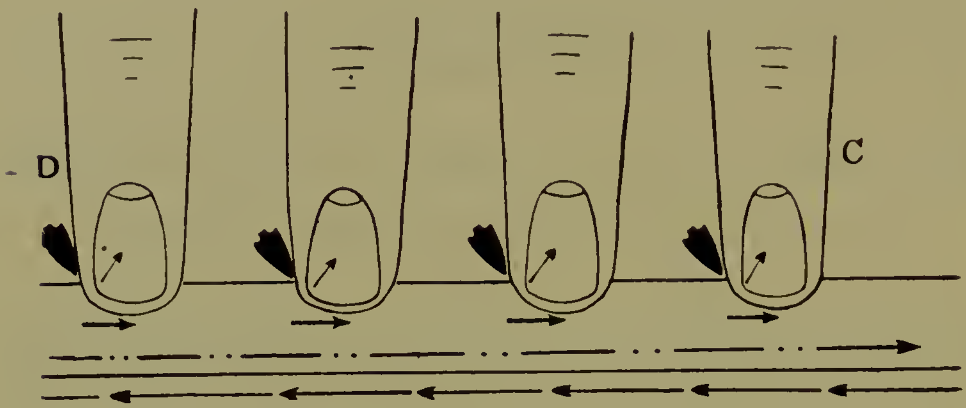
Before proceeding to a study of the Intermediate Ictus let us apply to the explanations which have been suggested for the two other varieties, the rigid test of time.

The direction of waves within tubes has been shown by von Kries (*cf.* p. 203) to be capable of determination, by a most ingenious method—at any one spot in their course. But, where a wave is capable of being felt and traced, a much simpler method is to time its passage at any two accessible spots. This can be done in the arm in the case of the wave-like process which constitutes the ictus.

The Direction of the Wave of Distal Ictus Determined by its Time-Relations.

Had the distal ictus, the continuity of which can easily be traced by shifting the finger by minute steps from the wrist towards the elbow, been a modification of the systolic or direct wave in its downward course .along the arm, the distal ictus at the wrist would have been a later event than the distal ictus at the elbow. This is not the case: on the contrary, as proved by Experiment (see p. 323), it is distinctly later at the elbow than at the wrist. We must therefore regard it is an ascending, and obviously as a rebound-wave.

FIG. 134.



The distal ictus traced up the arm by gradually shifting the finger. The long arrow with dots represents the *wave of the ictus*.

The Methods for Timing the Waves.

In all these comparative time determinations, thanks to the almost perfect synchronism* of the pulse events in the two arms (which in each subject needs to be carefully ascertained beforehand), the wave-transit may be conveniently compared in the two limbs. This is a more accurate process, especially when the fingers applied at different heights have to be alternately lifted in order to alternate the events, than to time one of them by the foot, trusting to the accuracy of the rhythm of the foot-beat, and also to the constancy of the cardiac rhythm during the interval.

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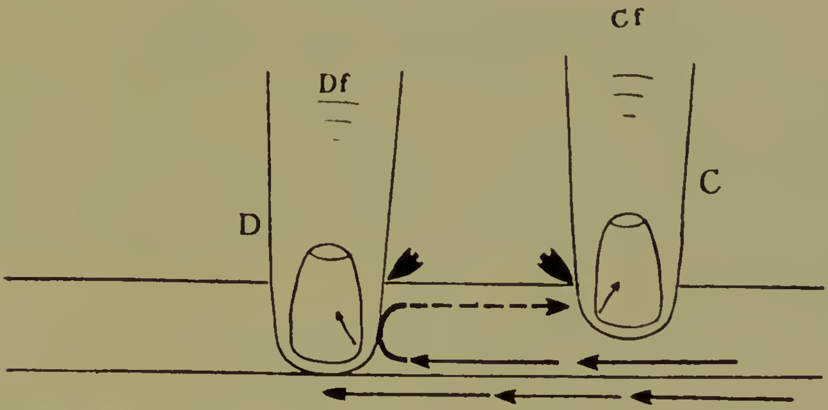
* For all ordinary purposes the two radial pulses, at identical levels, are synchronous; although, with due care, the right wave will be felt slightly earlier, owing to its shorter route from the heart.

Another time-proof of the reflux character of the distal ictus is obtained by the one-arm method.

Experiment XXXVI.

The delay of the distal ictus, pointing to its nature as a rebound, may be readily demonstrated by stopping the wave just above the wrist by the distal finger *Df.* This finger will then receive the impact of the direct wave. Meanwhile the central finger, *Cf*, is lightly applied, so as to feel the distal ictus. Instead of occurring before the event at *Df*, the ictus is perceptibly later. Thus the direct wave first travels down the artery under *Cf*, as far as *Df*, where it is reflected, and back again to *Cf*, which receives the stroke on its distal side.

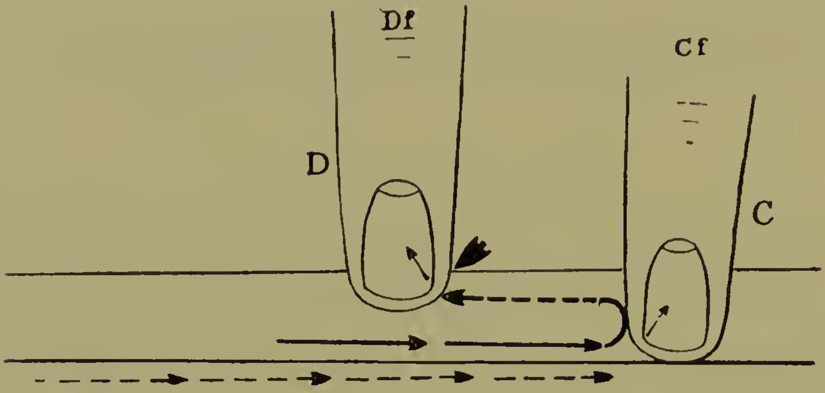
FIG. 135.



Mechanism of the distal ictus at *Cf*, *Df* being used as block. The sensation at *Cf* is later than at *Df*. (*Cf* is here represented pressing too deeply into the artery).

The same experiment may be carried out with the anastomotic pulse. A similar delay occurs in the wave: this is found to be due to a rebound of the anastomotic wave.

FIG. 136.



Same mechanism as in the preceding case, reversed in connection with the anastomotic wave.

The Relative Delay of the Proximal Ictus as Compared with the Distal Ictus.

If our estimate of the mechanism of the distal ictus be correct, then, precisely on the same principle, the proximal ictus, even at the wrist, should be later than the distal ictus.

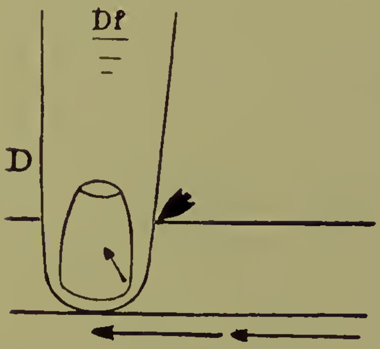
Experiment XXXVII.

The experiment cannot be tried with one finger; and, if only one arm be used, the only way would be to ascertain the rhythm of the distal ictus and keep up the rhythm with the foot; and to compare with the latter the actual rhythm of the proximal ictus.

A simpler and more reliable method is to compare the two beats simultaneously at identical levels in the two arms of any subject.

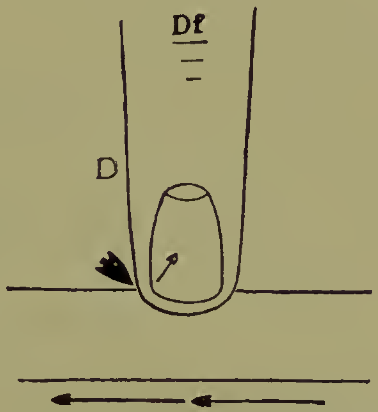
The same experiment can be carried out by the observer in his own case, by placing the hands palm to palm, so that the fingers of each hand extend up the opposite arm.

FIG. 137.



The proximal ictus (obtained in one arm, with pressure v), slightly later than the distal.

FIG. 138.



The distal ictus (obtained at the same level in the other arm, with pressure ii), slightly earlier than the proximal.

In this way it will be ascertained that the distal ictus occurs fractionally earlier than the proximal.

This result is entirely consistent with theory. The proximal ictus (which must be carefully distinguished from the earlier impact of the systolic heart-wave) is reflected from almost the same peripheral region as the distal ictus. Whilst however the latter rebound follows a straight upward course, the former, owing to the block in the radial artery, must travel up the ulnar artery* to its origin, before it can be conducted down to the proximal side of the observer's finger.

In conclusion we may regard it as fairly proved that the distal ictus is a rebound-wave, and that the proximal ictus is also a rebound-wave, but one having a centrifugal course.

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* Or some large collateral branch of the radial.

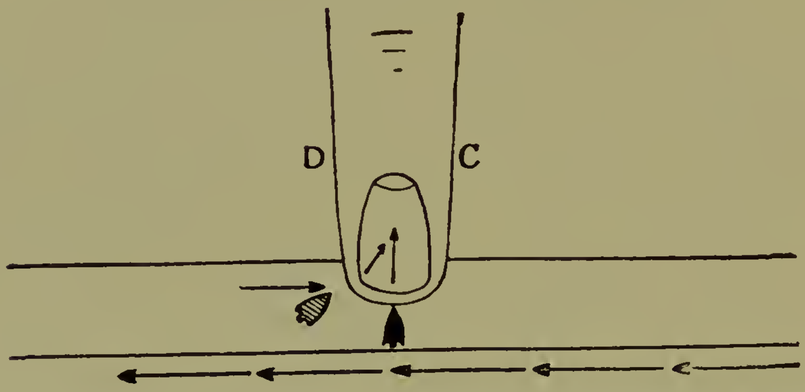
CHAPTER V.

THE INTERMEDIATE ICTUS.

Its Mode of Production.

As the name indicates, this is a half-way event between two more prominent ones; it may even be regarded as a combination between them. By a gradual increase of pressure ii, the distal ictus loses more and more of its lateral character, and advancing under the pulp of the finger, becomes, at pressure iii, the intermediate ictus. In the same way a further increase of pressure causes the stroke to incline further and further towards the proximal border, until degree iv of pressure is reached, when, rather

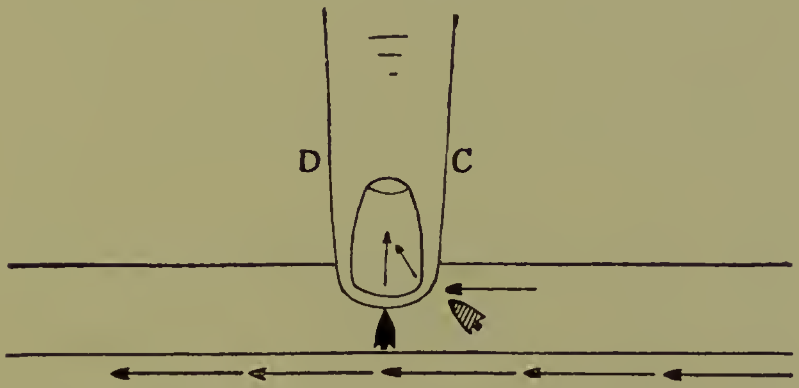
FIG. 139.



The black arrow-head represents the intermediate ictus setting in, when pressure ii is increased to pressure iii.

more suddenly, the ictus escapes from under the pulp to the side of the finger. The transitional character of the intermediate ictus and its double connection

FIG. 140.



Onset of the proximal ictus at a further stage of pressure.

with the neighbouring events are thus very plainly marked. Whether this ictus be felt by the conjoined sides of two fingers, by the central of three fingers,

FIG. 141.

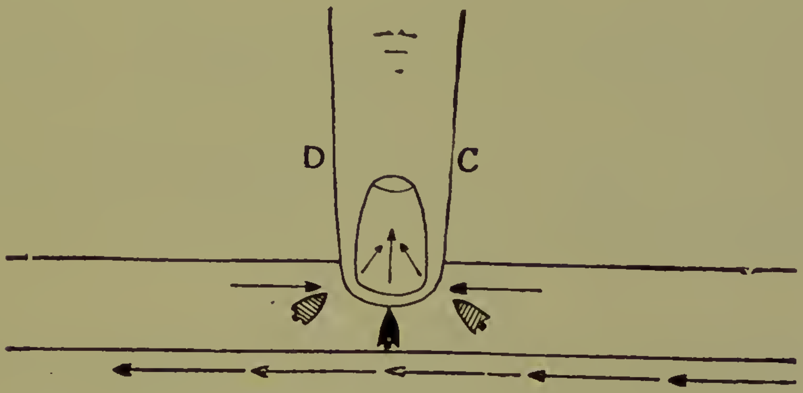
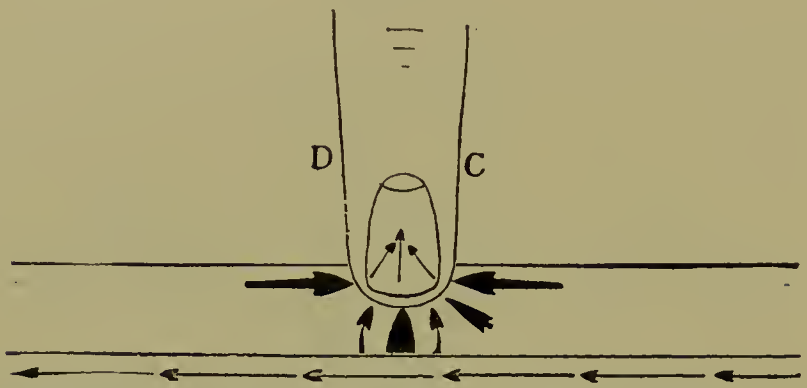


Diagram illustrating the double relation of the intermediate ictus with the other two forms of ictus.

or by the two middle fingers of a group of four, its mechanism and significance are the same. We may regard it as arising from the combination, we might almost say the conflict, between two waves, which we may identify as the ascending or centripetal rebound-wave or wave of the distal ictus, and the descending or centrifugal rebound-wave, from which

FIG. 142.



The thin arrow-head represents the onset of the systolic wave before the moment of the ictus. The mainly axial direction of this ictus is figured by the group of arrows beneath the finger-tip.

the proximal ictus is derived. It is understood that these two waves are superadded to the systolic heart-wave, which continues to flow; but that the beginning of the heart-wave is an earlier event, not directly concerned in the production of the ictus. The mechanism of the intermediate ictus obviously depends upon the relations subsisting between these two waves of rebound, and upon their relations to the pressure of the finger.

The Ascending and the Descending Rebound-Waves Compared as to their Time and Size.

On page 313 it is set forth that the distal ictus must occur fractionally earlier than the proximal. Had the interval in time between the two waves in question been less minute, and their length exceedingly small, it might have been doubted whether they could have met under the pulp of one finger. Their meeting is facilitated by the results of the pressure employed.

Pressure iii, whilst it places the finger *Df* in a favourable position for intercepting and for feeling any rebound ascending from the hand, so far reduces the size, and delays the transit of the systolic wave, that its distal rebound becomes imperceptible, and the ictus ceases to be felt distally. The main-wave and the reflux-wave are both slowed at the section of the artery which has been temporarily narrowed, whilst their pressure is locally increased. By this slowing in both transits, the ascending rebound-wave loses much of its advance on the descending rebound-wave. The latter, it will be realised, has not been subject to these modifying influences and preserves its original time, and its volume undiminished.

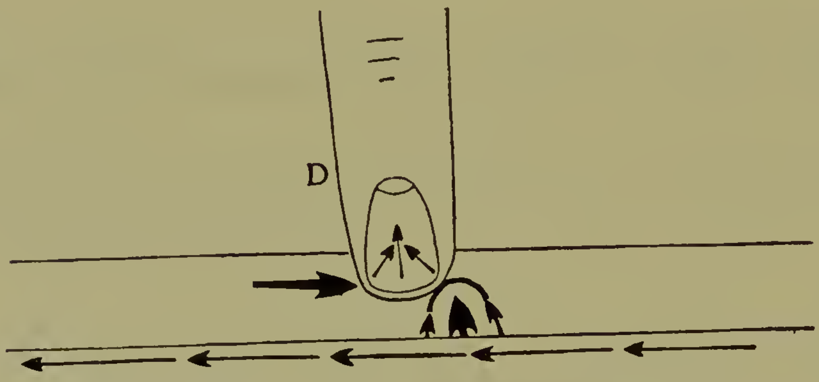
The Finer Detail of the Intermediate Ictus.

Thus the two waves will meet under the finger; but we may expect the sensation produced by them to be of greater duration than that of either the distal or the proximal ictus, both of which are more or less flash-like. Observation fully confirms this expectation. If capable of being appreciated by the touch, the inequality of the two opposed waves and their minute difference in time would furnish tangible evidence of the composite character of this variety of ictus; but it should not be forgotten that the transitional character, upon which we have insisted, is in itself a source of much variety in the sensations to be obtained by the finger. Moreover, the range of pressure which has been included under the degree iii represents gradations capable of producing appreciable modifications in the feel of the intermediate ictus.

The Two Component Waves and their Time-Difference.

Perhaps other observers may be as fortunate as the writer in tracing in it (under the favouring circumstances of a slow and moderately strong pulse and of appropriate finger-pressure) the two opposed waves. It would then be noticed that the earliest feeling is experienced under the distal portion of the pulp of the finger, and gives the impression of a thin wave, centripetal in direction. This wave cannot be followed very far under the pulp, but seems to stop abruptly before it has progressed half-way. Meanwhile another more prominent event would have

FIG. 143.



Separate perception of the two constituent parts of the intermediate ictus.

diverted attention to itself—viz., the coming of the more voluminous descending rebound-wave. This takes a pronounced effect on the finger, which seems to be lifted by it; and it may readily mask the distal factor altogether.

Indeed if the attention be centred, from the first, upon the proximal wave, the distal event cannot be perceived. This is probably the most striking illustration of the efficacy of the timing-method suggested on page 87.

By it we are enabled in this case to analyse into two periods a momentary event enacted under the mere tip of one finger. We know the distal factor to be the earlier one because, if we concentrate our attention upon it first, we succeed in feeling it, without ceasing to feel also the proximal event. So slight however is this priority that it can only be grasped by the earliest effort of attention; in the absence of which the more prominent, though slightly later sensation, entirely eclipses the weaker one.

Returning now to the descending rebound-wave, we are able to follow its diminishing volume as far as the middle of the surface included under the pulp, or a little farther—and there it abruptly vanishes.

The Site and the Direction of the Intermediate Ictus.

The impression received by the finger is—as the preceding description may have succeeded in explaining—that the ictus is given in this case mainly by the descending rebound-wave; and that its site is mainly the proximal part of the interval under palpation.

Since the proximal factor is so much more prominent than the distal, and since its descending character is thoroughly appreciated by the touch, the intermediate ictus as a whole conveys the sensation of a descending or centrifugal beat.

The Thrill sometimes Perceived in the Intermediate Ictus.

Thrill is another detail apt to be noticed in some pulses, apparently as a result of some definite degree of pressure. It is inconstant in its occurrence; and it may be difficult to elicit again, even in a subject which had previously yielded it. We must defer the discussion of this phenomenon till later.

CHAPTER VI.

WHAT IS THE ICTUS?

THE way is now cleared for a discussion of the spontaneous or natural ictus, such as it is observed in the absence of any tactile interference, as a visible event, over the site of any superficial artery.

The Visible Features of the Ictus: Its Retrograde March.

When our inspection is limited to a single pulsating spot in any artery, the eye tells us nothing more than the sphygmograph has succeeded in teaching us. The ictus is a sudden flash-like commotion of the artery. It is associated with a *distinct rise*, except in situations where the artery is tied down, as in the dip of arterial curves: in these situations there may even be a recession of the artery, instead of a rise. The sphygmograph also registers a rise; and this enables us to identify the visible rise as due to increased arterial pressure occurring at that moment; a conclusion which agrees with the sensation perceived when the finger is even very lightly applied.

When however an opportunity offers of watching a continuous length of artery (say, two or three inches), or when, by a judicious disposition of the limb, distant spots such as the wrist and the bend of the elbow are brought within simultaneous vision, any keen observer may notice that the rise of the ictus is not absolutely synchronous over the whole distance, but appears to progress as a very rapid wave, and in a centripetal direction. It is strange that this striking appearance should not have been observed, or, if ever observed and described, should not have been utilised by physiologists.

Ocular Demonstration of the Retrograde March of the Ictus.

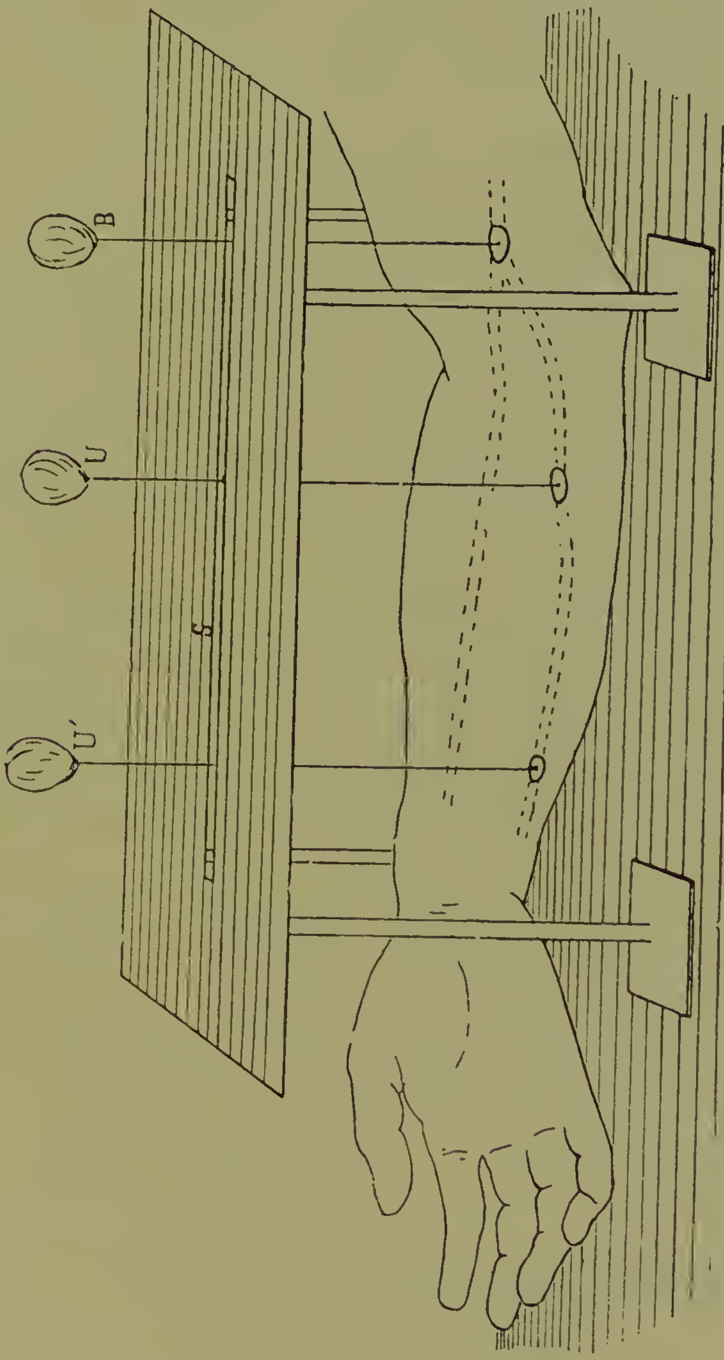
In presence of the hard fact of the direct course followed by the pulse-wave from heart to periphery, a backward course of the pulse-beat was so improbable that it was deemed necessary to test the correctness of this visual impression by some more tangible method.

A very suitable subject for experiment came under my care. Patient B., æt. 59, recovering from bronchopneumonia, presented an arterial abnormality in both arms, the ulnar artery being to a large extent superficial, and extending subcutaneously from the brachial as far as the wrist. He had frequently noticed and pointed out to fellow-workmen the unusual beating in his arms, which were very muscular.

Experiment XXXVIII.

The following method was adopted for testing the time of the ictus at different sections of the abnormal vessel in the right arm. Small discs of cork intended for application over the course of the artery were

Fig. 144.



Demonstration of the priority of the ictus at the periphery, in a subject whose ulnar artery took a superficial course.

each provided with a long thin wire, terminating at the upper end in a tuft of cotton wool; the tufts were allowed to project, through the slit *S*, above the horizontal piece of cardboard supported over the whole length of the arm. The disc B was fixed with a strip of plaister over the termination of the brachial artery, the disc U—over the first part of the abnormal artery, and the disc U—over its termination at the wrist.

The slight weight of the pieces of wire and their mode of fixation, were such as to make their pressure resemble the lightest form of pressure from the finger.

On watching the movements imparted by the ictus to the tufts of cotton, that belonging to the wire U (which moved more extensively than the other two) was noticed unmistakably earlier in its shake, by a trifle, than B; and U′ appeared to move, with each beat, slightly earlier than U.

When all three tufts were in visible motion, I desired five unprejudiced observers, nurses and patients of different ages, to tell me which of them moved first: their invariable answer, given independently of each other, was that U′ was the first to move.

I finally took my own observation again, looking straight up the cardboard from the wrist end, and I was convinced as before that U′ moved before U. The experiment left no doubt in my mind that U moved before B, and U′ before the other two wires.

Tactile Demonstration of the Retrograde March of the Ictus.

The result of this experiment was in reality a confirmation of previous tactile observations made by myself in other subjects. Patient B. afforded an excellent opportunity for testing their accuracy by the sensations of other observers; and on a subsequent occasion, the tactile time-determination was undertaken in the same patient, but without any instrumental aid, by myself and my clinical clerks, Messrs. Watson and Walker.

Experiment XXXIX.

The method employed was that of timing the beat of the wrist with the foot, and comparing its rhythm with that of the ictus felt at the upper end of the abnormal artery. All three observers agreed in finding that the distal ictus at the wrist preceded that at the bend of the elbow. The same impression was also obtained by looking at the visible beat in these two situations.

*It was thus proved, by the concurrent testimony of sight and of touch, that the ictus follows, in the arm,** *an ascending or centripetal course*;—a fact fraught with weighty deductions touching the most important questions in sphygmology.

THE MECHANISM OF THE ICTUS.

The finger, which in this investigation has shown itself superior to the sphygmograph as an instrument of analysis, has enabled us to distinguish three waves, in addition to the anastomotic wave, viz.:

(1) The Pulse-wave or Systolic heart-wave;

---

* It is hardly necessary to state that the experiment was repeated with identical results in a variety of subjects, and that what is true of the arm was also found to apply to the lower limb.

(2) the Descending wave of rebound;

(3) and the Ascending wave of rebound;

and it has also demonstrated the direction of each of them.

By means of the touch we have also verified the sphygmographic teaching that the acme of pressure does not accompany the onset of the heart-wave, but is due to a superadded wave.

Lastly, we have learned from the finger that there is yet a fourth wave, probably of a composite kind, the *wave of the ictus;* and that this wave follows a centripetal course. With these elements in hand our task is easy.

The wave of the ictus, being centripetal, must include, and must be for the greater part contributed by the only centripetal wave mentioned above, viz., the ascending wave of rebound.

In a general way it may be stated that the ictus is produced by the ascending wave of rebound. This in itself is a great point gained. Still, important questions remain, an answer to which may lie beyond the competence of touch:

(*a*) Is the wave of the ictus strictly identical with the ascending rebound-wave?

(*b*) Which phase of the ascending rebound-wave is concerned in the production of the ictus?

(*c*) Is the ictus the product of the ascending rebound-wave and of the systolic heart-wave alone; or is the conjunction with them of the descending rebound-wave an indispensable condition?

On these questions we can only venture to offer comments and suggestions.

Distinction between the Wave of the Ictus and the Ascending Rebound-Wave.

(*a*) The wave of the ictus may be regarded as a wave of maximum pressure. Although occurring within the span of the heart-wave and of the ascending rebound-wave, it coincides only with a brief section of each of them. The great length of the heart-wave is well known to us, and we must admit that its reflection must also possess almost identical length. The wave of the ictus is not conterminous with either of these waves, and in that sense not identical with the rebound-wave in particular.

In the second place, it seems to be obvious (and this point is very well brought out in von Frey's diagram, Fig. 101, p. 211) that the onset of the rebound-wave, and therefore also its acme, must, in its ascent from the hand to the shoulder, encounter very different phases of the heart-wave; and that the maximum pressure will be obtained, for each spot, from the combination of different phases of the two waves. In this sense again "wave of the ictus" and "rebound-wave" are not identical expressions.

The Position of the Ictus in the Rebound-Wave.

(*b*) The phase of the rebound-wave concerned in the ictus is an early one, even in those more central situations last to be visited by the ictus. This statement is based upon the early occurrence of the ictus in the course of the pulse-wave, and upon the fact that the highest pressure is attained, both in the heart-wave and in the rebound-wave, at a comparatively early period. Beyond this general statement it is at present impossible to venture any opinion.

The Descending Rebound-Wave in Connection with the Ictus.

(*c*) The difference in time between the ascending and the descending rebound-waves has already (in connection with the intermediate ictus, p. 316) been shown to be very slight. This circumstance tends to support the view that the two rebounds are associated in the production of the ictus. Another argument to the same effect might be derived from the fact that, at any one spot, the two rebounds would reach their maximum almost simultaneously,—and that their conjunction would therefore be most likely to bring about a shock such as the ictus with which we are familiar.

It cannot be gainsaid that the heart-wave and the ascending rebound-wave appear to be capable of furnishing the ictus without additional help. We should then expect to trace the appearance of the descending rebound-wave, as a separate event, in the close neighbourhood of the ictus. This possibility should be remembered in studying the normal sphygmogram.

The anastomotic wave, where it occurs, also possesses an intimate connection with the ictus. We have purposely refrained from any allusion to it, reserving this matter for separate consideration.

SUMMARY OF OBSERVATIONS CONCERNING THE ICTUS; AND CONCLUDING REMARKS.

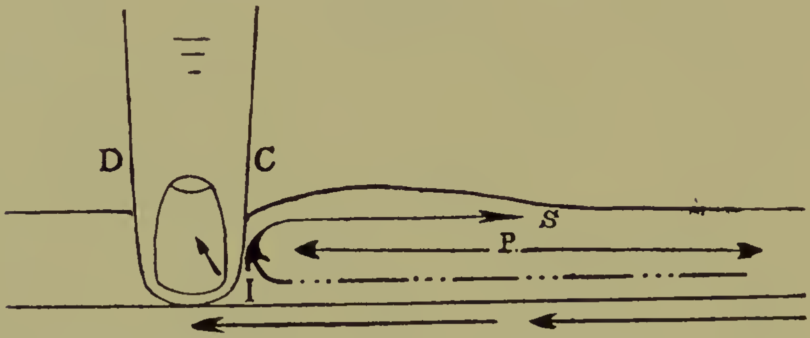
The Mechanism of Ictus.

What, then, is the ictus? We may regard it as a sharp and fugitive pressure raised by two positive waves, meeting from opposite quarters in the body of the long systolic-wave. We have seen that, in its onward course, the systolic-wave glides easily under a partial obstruction such as that of pressure ii; not so its rebound, the sudden shock of which, striking the peripheral side of the finger, has been termed the distal ictus. One of the two opposing waves is therefore the rebound of the systolic-wave from the hand. What is the other?—the systolic-wave itself? Doubtless this contributes greatly to the strength of the ictus: but there are reasons (see anastomotic pulse, p. 349) to suspect that the systolic-wave is reinforced by another wave of rebound descending with it towards the hand. The high pressure set up in the artery by the three waves as they meet would, according to this view, constitute the ictus.

The ictus, in this sense, might be called a percussion event, a collision. The percussion takes place between two moving forces. If one of them were a stationary obstacle, the result would be analogous. This is seen in the case of the proximal and of the distal ictus. In a comparable instance, that of a ligatured artery, the vessel, not being free to elongate, suffers dilatation instead, as described by Marey and by Oliver. A similar process must take place under ordinary circumstances at the periphery. Meanwhile, above the seat of compression, the rebound-wave becomes a travelling obstacle: and it may be difficult, higher up in the arm, to tell whether the wave and its ictus were of the spontaneous unmodified kind, or artificial.

The preponderating share taken by the rebound from the hand is shown by the retrograde character of the natural ictus, and by the fact that a degree of finger pressure which causes a shock to be felt on the distal side of the finger, does not suffice to make us feel any shock from the systolic wave, or from the descending rebound-wave, on the proximal side of the finger.

FIG. 145.



Diagrams of the pressures within the blocked artery at the moment of ictus. P, the mean arterial pressure; *S*, the systolic wave reflected; I, the ictus, due to the conjunction of the descending rebound-wave (dotted arrow) with the systolic wave.

On the other hand it has been shown that stronger pressure made on the artery elicits a powerful proximal ictus: and we note that the maximum sensation of this proximal ictus is not obtained by the finger producing obliteration, but a few lines above the latter.*

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* This increased pulsation is described by Dr. G. Oliver as the Expansile Reaction (see *Practitioner*, April 1893).

On the contrary, the distal ictus is most strongly perceived by the finger which exerts the slight pressure, and less strongly by any finger applied a few lines below the latter.

The Relative Time of Ictus.

The proximal ictus occurs earlier the higher in the arm the obliteration is made; this is not the case with the natural ictus. Indeed, careful observations with the eye or with the finger reveal the unexpected fact that the natural ictus occurs later at the bend of the elbow than at the wrist. The time difference between the distal ictus at the wrist and the proximal ictus above is greater the higher in the forearm the latter observation is taken. The conclusion is that the ictus is produced at each spot by the conflict of the ascending or distal rebound-wave with the descending rebound-wave coupled with the heart-wave.

To look for stability in the time-relations of the ictus at different parts of the arterial system would not be consistent with that which we know of the local variations of the pulse. The rate of transmission of the direct wave is subject to perturbations which must be reflected in its rebound; but the rebound-wave itself has also variations connected with passing conditions at the periphery.

Marked differences will thus arise not only in the size but in the time of the ictus at different periods. At one time the ictus may be markedly retrograde. In the same arm, at another moment, any want of synchronism may be difficult to identify, so great is the influence of the arterial conditions as to patency and as to tension, and of the passing changes in cardiac action and output.

Lastly, each large district or limb has its own average time for the ictus. For instance, though the ictus at the elbow is later than at the wrist, the carotid ictus is earlier than the radial.

CHIRURGICAL SOCIETY

CHAPTER VII.

THE ANASTOMOTIC PULSE.

Frequency of Occurrence.

An elementary description of this variety of pulse has been given on p. 103. In the adult an anastomotic pulse appeared to be more often present than absent. Of 39 adults, examined by the author, with the kind assistance of Dr. E. Graham Little, 27 had an anastomotic pulse.

In children (up to the age of 12) the same frequency is not observed. Among 24 cases an anastomotic pulse could be found in nine only; it was either absent or escaped recognition in the remaining fifteen.

Larger numbers are required for percentages, and might be easily obtained. The examination needs much care, the anastomotic wave being, with inadequate manipulations, easily overlooked, or wrongly thought to be present. In children the small size and active muscular reaction of the artery and the thickness of its coverings are very apt to disguise the presence of the wave.

Obliteration kept up for a sufficient time will ultimately call forth the indirect beat in practically all subjects. In some cases, and these probably form a large group, it appears and disappears spontaneously under varying influences, presently to be mentioned.

The Source and the Channel of the Anastomotic Pulse.

The anastomotic pulse is nothing more nor less than the direct pulse deflected into an upward direction by the curvature of its peripheral channel. *The channel of anastomosis* may not be always the same.

It is usually accepted that the anastomotic wave felt in the radial below the obliterating finger is propagated from the Ulnar artery, through the *Superficialis Volæ,* the size of which in the individual would doubtless influence the occurrence of reflux; but transmission perhaps partly takes through other channels.

Its Mode of Production.

The fact that this peculiarity is not always a "permanent," but often an intermittent one, points to a functional mechanism.

The *Superficialis Volæ* artery would be capable of transmitting (although it might not at all times transmit) a sufficient wave. If the intermittent causes for an increased patency of the vessel should become permanent, the whole group of cases might perhaps be explained in this way, without the assumption of any organic change.

Two opposite conditions of the peripheral circulation might lead to increased diameter of a vessel of the size of the *Superficialis Volæ* :

(1) A local or general arteriolar relaxation in which this artery would participate.

(2) A local or general capillary and arteriolar spasm, whereby greater pressure would be thrown upon the artery, with corresponding pulsatile dilatation.

Its Constituent Elements and its Relations.

Viewed in itself, apart from its connection, the anastomotic pulse consists of all the elements proper to the ordinary pulse. Its study implies a consideration of the various factors of the pulse: (1) the blood-stream, its pressure and its velocity ; (2) the pulse-wave (including rise, apex, and fall), its pressure and its velocity ; (3) the ictus and its modifications ; (4) the secondary waves, and especially the dicrotic.

In reality an anastomotic wave can have no isolated existence, except in our imagination. It is bound up by mutual relations of a complicated order with the direct radial pulse on the one hand, and with the peripheral circulation on the other. The exchange of these reciprocal influences modifies not only the anastomotic pulse, but the main pulse also, in the same proportion.

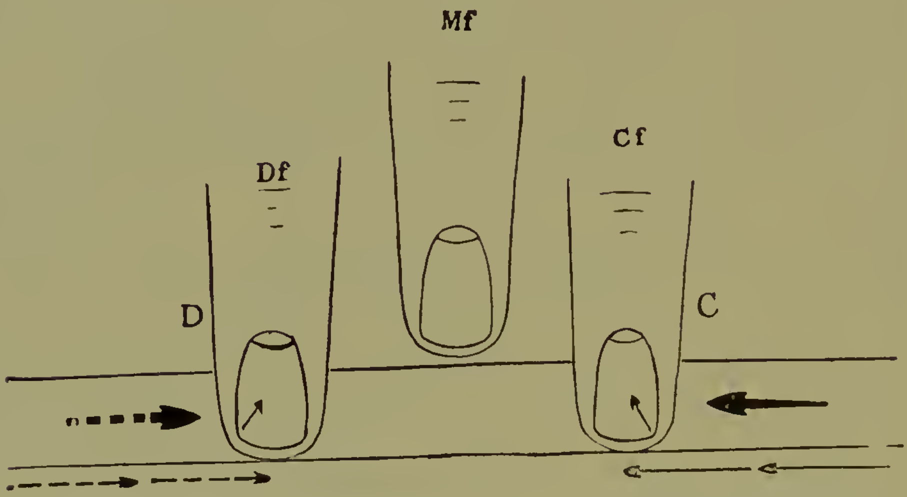
The Identification of the Anastomotic Wave.

Our usual means of identifying the anastomotic-pulse is to stop the direct pulse ; but, in so doing, we exclude our most important object for study. We have yet to discover in what special way the tactile character of the main radial pulse is modified by its combination with the anastomotic pulse. That the inter-actions and reactions between the two pulses must have as their practical effect to impress upon the pulse at the wrist some definite and tangible peculiarity, admits of very little doubt; and it remains an important duty for tactile analysis to isolate this distinctive feature. Meanwhile we are limited to the method by obliteration, as a means of identification.

The Anastomotic Pulse Modified in the Act of Identification.

A moment's reflection will show that this preliminary manœuvre entirely changes the conditions we seek to investigate. Henceforth we are dealing with an artificial product; and at the same time we are dealing with a yet more profoundly modified radial pulse. Observations made under these ab-

FIG. 146.



Demonstration of the anastomotic wave by double blocking. The pulseless interval, where both pulses should meet, shows the great interference with the normal state.

normal conditions may have their use; they can however furnish no reliable evidence, at best perhaps inferences and suggestions, concerning the intra-arterial events such as they occur in the absence of any interference.

Two Distinct Objects for Study.

Our investigation necessarily consists of two sections:

I A study of the anastomotic pulse under the influence of occlusion of the radial artery at the wrist;

II A study of the anastomotic pulse in its normal relations to the direct radial pulse and to the peripheral circulation.

CHAPTER VIII.

THE BLOCKED ANASTOMOTIC PULSE: ATTENDANT ALTERATIONS IN THE CIRCULATION.

This Pulse Contrasted with the Direct Pulse.

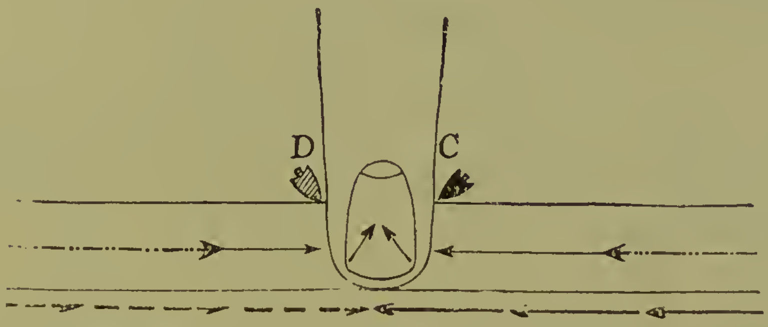
When a finger is applied firmly to the radial at the wrist, the anastomotic pulse and the direct (or distal and proximal pulses) are separated. Between them, since they are influenced by the same pressure, a very close analogy will exist.

More distant, yet traceable, is the analogy between the blocked anastomotic pulse and the natural radial pulse (such as it is felt in subjects free from anastomotic pulsation); at any rate, we should be able to recognise the same general features in both pulse-waves.

In the first place, the *systolic wave*—thanks to the rapid wave-transmission through the wide channel of the radial artery—would not be much later in reaching the wrist from below than by the direct route.

On the other hand, the *waves of rebound* special to the anastomotic pulse would follow quickly upon the onset of the systolic wave; for, in its journey round the palm, the wave feeds vessels which furnish a rebound both ample and of straight course, and therefore capable of reaching the finger with the least possible delay.

FIG. 147.



One finger used as block. The anastomotic *systolic wave* (fine arrow) only slightly later than the direct. The anastomotic rebound wave and ictus (dotted arrow) earlier than those of the direct pulse.

Radical differences exist, however, between the direct radial pulse and the blocked pulses, both above the obliterating finger and below it.

The block is abrupt, and does not resemble the gradually increasing character of the obstacle offered by the natural capillary resistance.

In the second place, although blood-waves are propagated as freely as before, the blood-stream is much modified in various particulars.

Local Alterations in the Circulation as a Result of Obliteration of the Radial Artery.

Various coarse changes in the circulation occur as a result of blocking the radial artery at the wrist:

(1) The most extreme change is the *reversal* of the

current in the radial portion of the palmar arch and in the *Superficialis Volæ*;

(2) Both above and below the block the blood-flow is much diminished, and close to the block it is suspended. The arterial calibre is not diminished, but rather seems to be increased;

(3) The fully maintained arterial diameter depends upon the blood pressure which is kept up at both blind ends, and which is composed of two elements: (*a*) the mean arterial pressure, and (*b*) the systolic wave pressures;

The Respective Changes in the Radial and in the Ulnar Blood-flow.

(4) Whilst, at the seat of obliteration, the arterial flow is stopped, at a distance from the block it is only modified; but in a very different way. In the radial the arterial flow is much diminished; in the ulnar it is increased in an equivalent degree, the difference being represented by the volume of blood for the arterial supply to the hand.

These coarse changes probably furnish the basis for finer changes of various kinds, some of which only can be alluded to:

The ulnar current probably increases in size;

The velocity of its stream probably increases;

The pressure is probably raised within the artery;

The rate of transmission of the wave would probably be increased proportionately to the pressure.

In the radial artery converse changes might be looked for, as regards the blood-flow and its rate; but pressure would be, up to a certain point, increased as a result of the rebound of the undiminished wave against the block, the positive pressure of the rebound-wave adding itself to that of the systolic wave.

The Changes in the Circulation within the Palmar Arch and its Branches.

Reference has been made to the reversal of the direction of the stream in a portion of the palmar arch. This produces a transient loss of pressure and of fulness in the distal portion of the obliterated radial, which gradually becomes charged again, the pressure rising to that of the channel of anastomosis.

The finer alterations which probably take place are beyond the reach of demonstration, but they may be inferred with some approach to certainty.

The early results, in the circulation of the hand, of an obliteration of the radial artery would be :

(*a*) A slightly diminished blood-supply ;

(*b*) A slightly diminished blood-pressure ;

(*c*) A slightly diminished vascular tension ;

(*d*) Corresponding modifications in the conditions of wave-rebound.

After a time, in the event of the obliteration being maintained, these slight changes would probably become less marked, owing to the gradually more ample vicarious blood-supply.

(*e*) In one respect previous conditions could not be completely restored. The loss of the radial pulse-wave, which should oppose the direction, but add to the pressure of the ulnar wave ; and of the radial ictus, which should reinforce the ulnar ictus, would continue to exercise its influence. Whereas the changes enumerated above would tend to retard the progress of the wave, this influence would tend to accelerate it.

(*f*) Lastly, the pulse-wave within the distal end of the obliterated radial artery would also remain under the influence of the unevenness in the calibre of the channel of communication. In the normal pulse the wave descends from vessels of larger to those of smaller diameter. This order is reversed in the radial artery below the obliteration, the wave ascending into a relatively wide artery through the narrow channel of the palmar arch, or of the *Superficialis Volæ*. In this transit a *negative* wave-rebound would arise, which would diminish by so much the positive pressure set up by other rebounds.

The narrowness of the channel would also have, *pro tanto*, a retarding effect on the wave.

CHAPTER IX.

THE BLOCKED ANASTOMOTIC PULSE: TACTILE PHENOMENA BELOW THE BLOCK.

Occasional Delay in Obtaining a Pulsation; and its Causes.

On making pressure at the wrist, we should not too hastily conclude that the anastomotic pulse is absent. In many subjects an interval of a few beats elapses before the anastomotic pulsation is thoroughly established. Its relatively prompt return warrants a conclusion that it was suppressed by the pressure, and justifies us in classing the case in the positive group.

A longer delay would probably enable us to feel an anastomotic pulsation in a considerable proportion of the negative cases; but this late expansion of the channels of anastomosis has a different significance, and we should nevertheless uphold the practical distinction which we have originally made.

Two causes may explain the temporary absence of pulsation below the obliteration: (*a*) In most subjects with small systolic wave it is reasonable to expect the sudden call made on the ulnar contents for the supply of the hand, to drain the anastomotic vessels of a great part of their blood and to cause them to contract. Each succeeding systole tends to restore the balance of the local circulation; but the anastomotic wave remains of small size and feeble; (*b*) This explanation does not apply so well to cases where the anastomotic wave regains a good volume, after being temporarily extinguished. A distinct explanation suits these as well as all other cases. When forcible pressure is made upon them, arteries will contract, even sometimes to obliteration. The spasm, however, is not of long duration, and, as stated on p. 164, it gives way to a stage of relaxation. The correctness of this explanation may be tested by the concomitant effects noticed above the obliterating finger. The proximal pulsation is, if not entirely suppressed, at least considerably reduced during the latency of the anastomotic pulse.

In some pulses the anastomotic wave is felt at once, full and strong. These are generally instances of large and lax arteries, which enable the peripheral circulation to accommodate itself at once to the new conditions.

The Sensations Conveyed to the Finger Placed Beyond the Block. The Anacrotic Character.

The wave in question is in all cases much softer than that felt above the block, and often needs for its recognition very light and delicate palpation. It gives the impression of a longer duration, of a slower ascent, of a broader summit, and of a less voluminous, less sudden, and less forcible ictus, than those felt above the obliterating finger.

The onset of the systolic wave can usually be felt, followed by a gradual ascent. Taken in conjunction with the rounded summit, these are anacrotic features such as arterial stenosis is apt to occasion. In this case the stenotic effect is probably produced by the interposition, between the two larger arteries, of the narrow channel of the *Superficialis Volæ* or of the palmar arch.

As stated elsewhere (p. 335), the elementary experiments which have been described in connection with the normal pulse can also be conducted in the case of the anastomotic pulse. The results are analogous, and need not be enumerated again. It may be well, however, in order to obviate confusion, to remind the reader that, when we use light pressure (that of simple contact), the pulsation felt is that which corresponds to the ictus. If, in the course of any deeper palpation, doubt should arise as to the relative time of any event, this can always be solved by relaxing the pressure, and ascertaining the time of the ictus.

The Anastomotic Ictus. The Relative Time of its Occurrence.

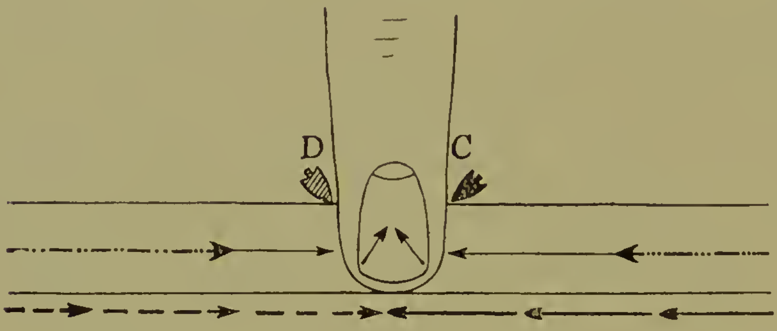
It is time to qualify the statement made on page 172, that "*Cf* would receive the direct, *Df* the anastomotic wave." The tangible event is in neither case so much the impact of the wave, which is only just capable of recognition, as that of the ictus.

The beat felt by the finger above the seat of obliteration has already been described in detail as the proximal ictus (see p. 306). The anastomotic ictus felt below the blocking finger has also the value of a proximal ictus, since it bears the same relation to the systolic wave.

Between these two beats (above and below the block), minor differences can be made out by the finger, and, in appropriate cases, also by the sphygmograph.—But among them none is so striking as the difference in time often observed.

Contrary to expectation, the beat below the block is unmistakably earlier in a large proportion of cases than that above the block. In eleven cases out of twenty-seven it occurred fractionally earlier than the beat above the seat of obliteration; and in one case it was sometimes earlier than, and sometimes synchronous with the latter. Additional observations have shown that this variability in the time relation in the same individual, is by no means of isolated occurrence.

FIG. 148.



The anastomotic ictus, D, usually earlier than the direct ictus, C.

The problem before us is intricate and presents two difficult questions: the priority of the anastomotic ictus in some cases, and its variable time in others.

The Method of Timing the Anastomotic Ictus.

In taking these observations I had the advantage of Dr. E. Graham Little's valuable assistance. At first the obliteration of the pulse was entrusted to him, whilst the writer's two hands were simultaneously engaged in feeling the pulse of the radial at the wrist, and of the brachial just above the elbow. This is doubtless the easiest method for the beginner.

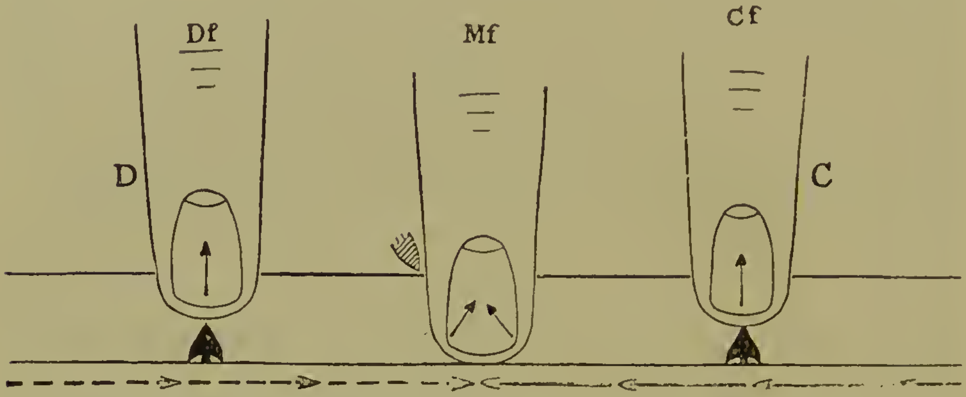
Soon, however, it was found possible to perform obliteration, as well as palpation, without assistance; one of the fingers of the left hand feeling the anastomotic pulse and the others blocking the artery above it; whilst a finger of the right hand was applied as before to the brachial artery.

In the course of the experiments it was noticed that, whenever the anastomotic pulse was earlier than the brachial, it was earlier also, by the same amount, than the radial beat immediately above the block. On putting this observation to a crucial test, the radial beat above the block and the brachial beat were found to be synchronous, as far as the finger could judge. To this there was no exception in any of the cases tried.

It was now clearly unnecessary to consult so distant a beat as the brachial; and it was possible for the fingers of one hand to obliterate the artery and to time the beat above and below. This facility enables the observer to time the two beats in his own pulse; and with practice this can be achieved with success. But in ordinary cases it is more satisfactory to use two hands, and to obliterate the artery with the hand feeling the upper beat, rather than with the other hand.

The differences in time observed in a series of cases are various : in some very slight, and apt to disappear or to oscillate from one to the other phase, in others very marked, so as to be appreciable to any untrained person.

FIG. 149.



Timing the anastomotic and the direct ictus with one hand. *Mf* as block, *Cf* and *Df* applied with pressure iii.

The Frequent Priority of the Anastomotic Ictus, and the Possible Causes of the Priority.

The synchronism found to obtain between the radial beat above the block and that of the brachial artery somewhat simplifies the difficulty. We may, at least provisionally, assume that during the wave transit along the radial and along the ulnar, time is not appreciably lost or gained. It must be at the periphery, and in connection with the rebounds that time differences are established.

Allusion has been made in connection with the natural ictus (see p. 329) to the share probably taken in its production by a descending rebound from the arm. The same rebound is also assumed to be a prominent factor in establishing the difference in time we are now seeking to explain.

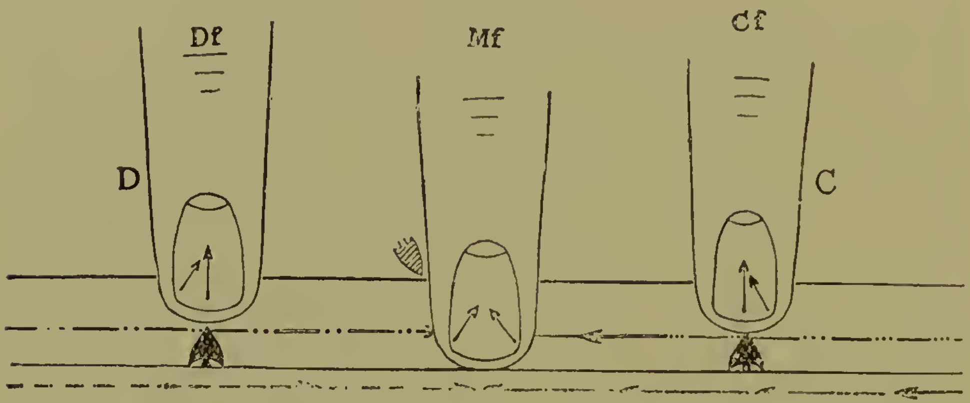
On the supposition that an ictus can be produced by rebound, its time of occurrence might be influenced in two ways: (1) The rebound would be retarded, as shown by von Kries (see p. 114), by the length of the arterial branches conveying the wave to the periphery, and the rebound from the periphery. Distance in these narrow vessels is not, as in the wider channels of the larger arteries, a negligeable quantity. This influence is therefore capable of being roughly estimated. (2) The second influence is one with which we cannot reckon, though we recognise its importance. At the periphery the delay of the rebound may be very different, according to the diversity of the tissues, and of the conditions of the circulation through arterioles and capillaries.

For the present we are confined to a discussion of the first of these influences. The arterial branches of the hand being so much shorter than those of the arm, we readily conceive that their rebound may occupy a shorter time in reaching the wrist, and, little time being lost in its transmission up the radial artery, may reach the elbow and the shoulder before the moment when the rebound-wave from the arm (of which it had encountered the beginning at the wrist) had run through its stage of prominence. This theory would explain the ascending march special to the natural ictus.

Let us now obliterate the artery at the wrist. The two opposing rebounds would be kept separate, and the acme of the hand-rebound would be felt earlier than the acme of the rebound-wave from the arm.

The priority of the anastomotic ictus provides us with a collateral proof that the proximal and the distal ictus are not merely due to the striking and rebounding of the systolic wave against an obstacle. For in a normal subject there is no conceivable circumstance under which the systolic wave could reach the more distant site earlier than the nearer one; and, at the wrist, an anastomotic ictus produced by the systolic wave would invariably be a later event than the proximal ictus, had this been the mechanism.

FIG. 150.



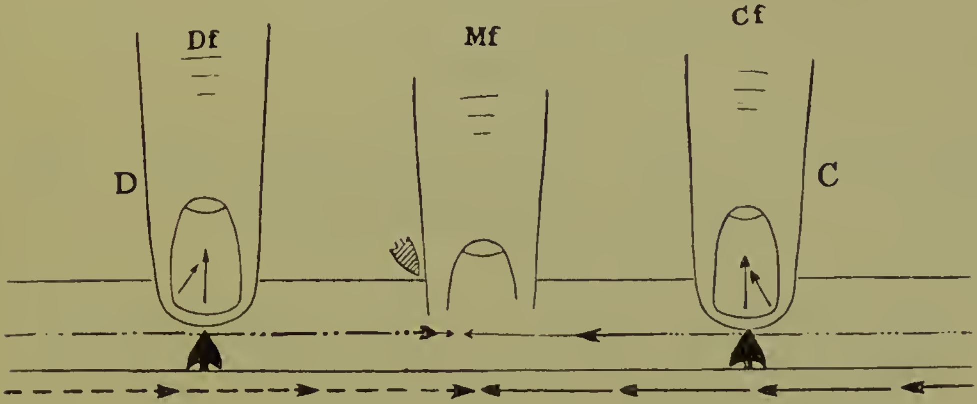
Mf receiving the anastomotic ictus. The ictus from the direct pulse has not yet struck *Mf*.

The head of the systolic wave must, as shown in Fig. 133 suffer delay in its anastomotic transit, and ascend to the wrist later than the direct systolic wave. Still the rebound from the hand may reach the observer's finger earlier, and convey an earlier ictus than the rebound generated in the long arteries of the arm, which subsequently travels down the radial artery to the proximal side of the finger.

The solution of the other difficulty is foreshadowed in the preceding remarks.

The delay in the rebounds may be readily assumed to be variable when we consider the changes constantly taking place in the size of the arterial branches on the one hand, and in the conditions of the arteriolar and capillary circulation on the other.

FIG. 151.



Same as preceding diagram, showing the time-relations of the tactile events experienced by *Mf*. The head of the two systolic waves (fine arrows) is followed, at different intervals, by the ictus. The anastomotic ictus has struck *Mf* as well as *Df*—the other ictus has not yet struck *Mf*, but *Cf* only.

The conditions prevailing at any moment in the arterial district of the arm and in that of the hand may be entirely different: at another moment previous relations may be reversed. The earlier occurrence of the anastomotic ictus would suggest conditions accelerating the rebound from the hand, or retarding the rebound in the arm; its later occurrence might be explained *vice versâ*. We are reminded in this connection of the possible influence of the two different ways in which an anastomotic pulsation is supposed to originate—in the one case by relaxation of the arterial channels with low arterial tension ; in the other case by constriction of the arterio-capillary district with high tension.

What has been said sufficiently shows the intricacy of the problem, and the extent to which we are still restricted to mere speculation.

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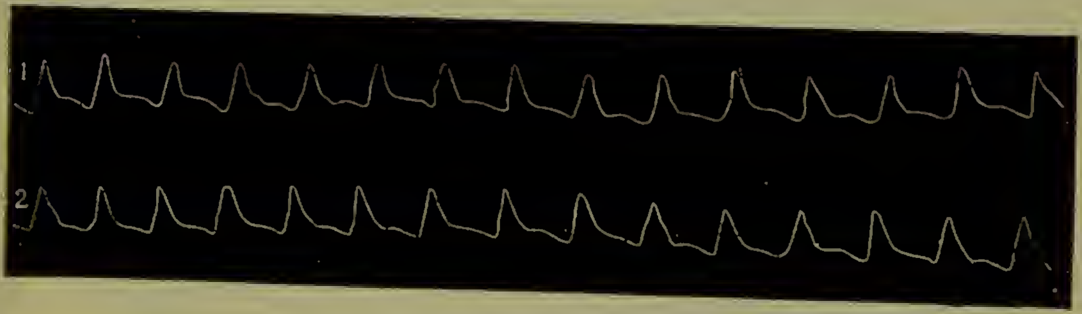
CHAPTER X.

THE SPHYGMOGRAPHIC STUDY OF THE ANASTOMOTIC PULSE.

Tracings taken above and below the Block.

The author is not aware, though they may exist, of any published tracings of the anastomotic pulse taken immediately after obliteration, except those of Marey,* obtained from the carotid of the horse. Marey's two tracings of the sound radial pulse from one arm and of the anastomotic radial pulse from the other arm are, owing to the long interval after the

Fig. 152.



Marey's sphygmograms of a normal radial, and of the other radial of the same subject three weeks after its ligature at the bend of the elbow; showing "identity." *Loc. cit.* p. 629.

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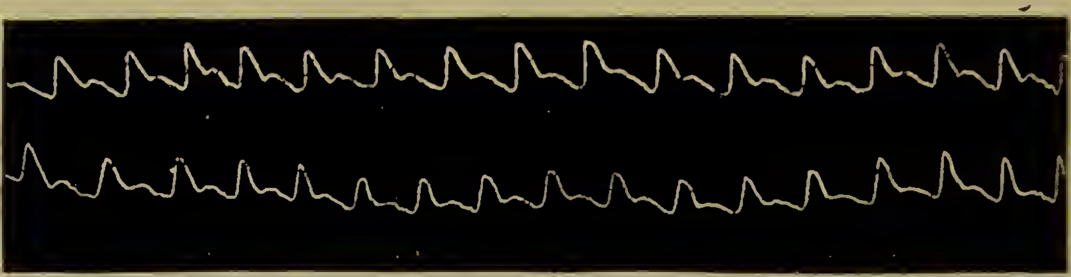
* *Loc. cit.* pp. 624–629.

date of obliteration, useless for the present purpose; but they show the interesting fact that, after lapse of three weeks, the anastomotic pulse-tracing may become indistinguishable from the normal (Fig. 152).

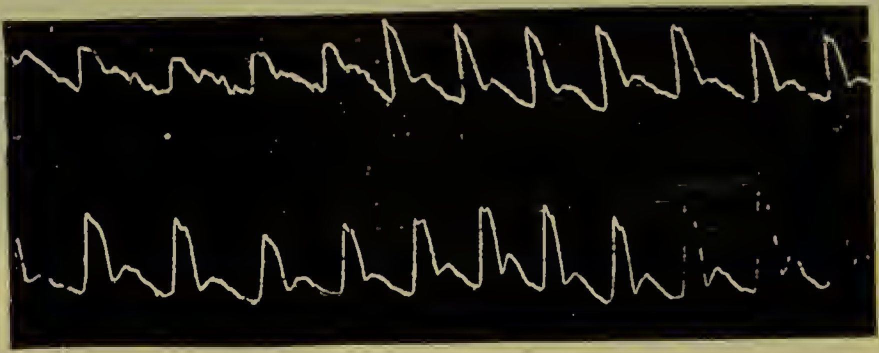
The tactile observations detailed above have the advantage of being entirely unprejudiced, the author not having turned his attention to the sphygmography of the anastomotic wave until after they were written. To what extent they correspond with the

Fig. 153.



Sphygmogram of anastomotic pulse (rt. radial) **taken ½ inch below the block.** The upper tracing was obtained with 70 grms. pressure; the lower with 50 grms. (Marey's Sphygmograph.)

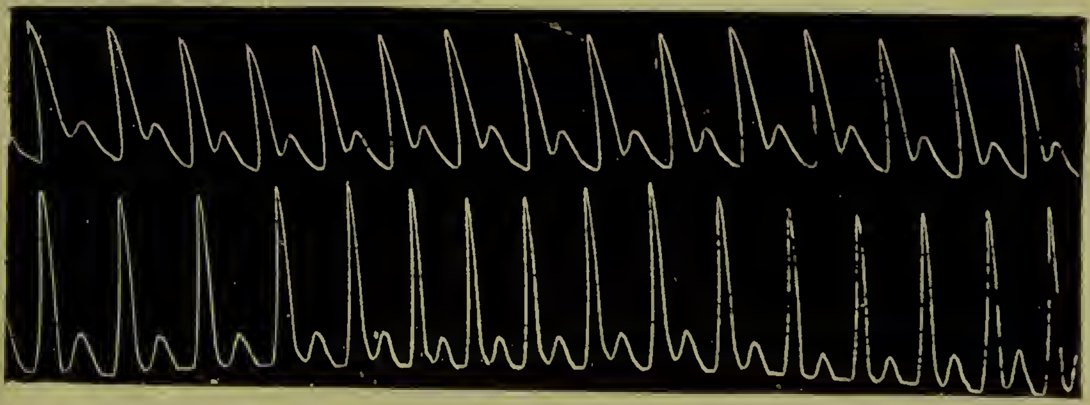
Fig. 154.



Sphygmogram from the same wrist, **taken ½ inch above the block.** The first five pulsations in the upper line are unreliable. Pulse rate 87. Pressure: upper line, 50 grms.; lower line, 120 grms.

sphygmographic rendering of the wave will be seen from the annexed tracings, with this reservation, that the tactile study was made from many pulses. and these are merely a few individual pulse-curves. The first is from an anæmic man, *æt.* 63, who had only that day left his bed after three weeks. This circumstance may account for the type of pulse noticed in Fig. 155, and for the size of the anastomotic wave, (Fig. 153) which, after lapse of a few days, was much less ample.

FIG. 155.



The same pulse immediately after removal of block. Pulse rate: 92. Pressure: upper line, 120 grms.; lower line, 50 grms.

With the help of Dr. E. Graham Little and of Dr. Hofmeyr, I succeeded in obtaining radial tracings below the block, above the block, and subsequently after removal of the obstruction, from the previously occluded length of artery.

The highly dicrotic curves obtained after removal of the pressure need not detain us now; they wlll be referred to again under the heading of "Dicrotism.' Let us turn first to the analysis of the pulse on the proximal side of the obstruction.

Analysis of the Sphygmogram taken above the Block.

Overlooking imperfections in the tracing, we notice the following well-marked characters:

(1) The line of ascent is steep, though not quite so rapid as that of the unobstructed radial tracing below.

(2) There is no anacrotism, and the primary apex is sharp and clean.

(3) There is a marked tendency to the formation of a plateau at the summit of the wave in some of the pulsations; but in all of them the descent from the primary summit is at first very gradual, until

(4) The sometimes very sharp secondary summit is reached. Are we to regard this as the so-called predicrotic wave? If so, it may be considered unusually early, unusually high in the tracing, and presenting somewhat unusual distinctness. We take special note of the absence of this event in the radial tracing below the block.

(5) The depth and rapidity of the fall which ensues are associated characters of dicrotism. They are more marked than in ordinary tracings; and the dicrotic notch tends to be a little more angular and narrow at its extreme point, although more open immediately above this than in the tracing of the unobstructed radial pulse.

(6) The dicrotic rise as a whole is slower, its obliquity being, with few exceptions, increased.

(7) The dicrotic descent inclines to be convex

rather than concave; here and there the faintest indication only can be seen of a post-dicrotic wave, which is absent from the other tracing.

So far as the relative levels of the lever at various moments of the wave-transit may be regarded as expressing the existing intra-arterial pressures, it must be concluded that the tracing of the pulse above the block differs from that of the unobstructed pulse in the following important respects: (1) in the greater width of its summit, which presents a double acme; (2) in the more oblique—that is, slower—fall of the line of descent, which is free from the scoop-like deflection at its lower end seen in the other tracing; (3) especially in the shorter fall, whereby the dicrotic events take place at a higher level in the tracing; (4) in the resulting less extensive and more oblique dicrotic rise; (5) in the longer persistence of the dicrotic elevation; and lastly (6) in its less rapid fall; for in most of the individual waves the descent is not completed before the foot of the ensuing upstroke is reached.

Reference is made elsewhere (see p. 397) to the earlier occurrence of the dicrotic summit in the tracing taken above the block.

This peculiarity is made more obvious in Fig. 168 by the lines introduced into the tracing.

In all these particulars the two curves differ. They do not therefore bear out von Frey's opinion that obliteration of the artery below the sphygmograph causes no modification of importance in the tracing.

Analysis of the Sphygmogram taken below the Block.

The first point noticed in the tracing of the anastomotic pulse is its smaller size, and its relative want of definition.

In these, and in all other particulars the tracing differs even more widely from the unobstructed pulse-trace than from that which we have just described. Every purpose will therefore be answered if we compare it with the latter only.

(1) The line of ascent is perceptibly less vertical without presenting marked obliquity.

(2) There is no anacrotism, but the end of the upstroke is slightly rounded; this feature contrasts with the sharp summit described above.

(3) There are a bluntness and a width of the wave at its top which remind us of the tendency to plateau-formation in the other trace, a tendency which is only faintly indicated in two or three pulsations in this one.

(4) There is no second acme; and beyond the width and squareness of some of the summits, no indication of a predicrotic rise.

(5) The obliquity of the fall is very marked, and contrasts with the more rapid drop of the other tracing. The dicrotic notch is shallow and cupped, but in a few instances it is fairly angular.

(6) The dicrotic rise is correspondingly stunted and slurred, presenting none of that sharpness seen in some portions of the other tracing. Its obliquity

is considerable, and the swell of the wave is long-sustained, passing with slow gradations into the descending limb.

(7) A faint indication of a post-dicrotic notch is perceptible in some pulsations; but its genuineness is not above suspicion.

(8) In two particulars the latter part of the trace differs from the other type. The obliquity of the line of descent, although fairly sustained, does not always extend to the foot of the upstroke, and the main level of the dicrotic events is a little lower. These features may be regarded as indicating a lower vascular tension; and lowered tension, with imperfect definition of individual wave-characters, are precisely the results we might expect in an arterial sac supplied by a relatively small channel. Indeed there are analogies between the conditions and tracings in question and those belonging to some aneurysms.

It is noteworthy that the "anastomotic" tracing shares with the upper tracing the peculiarity of an early dicrotic summit.

The respiratory oscillations are easily recognised in all three tracings.

No clue is supplied by a comparison of the tracings as to which of the two sphygmographic wave-summits was the earlier one. Careful simultaneous tracings taken with sufficiently rapid revolution of the cylinder would easily settle this point.*

Meanwhile we are bound to trust in this matter to the testimony of the touch, when at the hands of independent observers ; it leads to identical conclusions especially since we have been able to verify its accuracy experimentally in the analogous determination of the priority of the ictus at the periphery (see p. 325).

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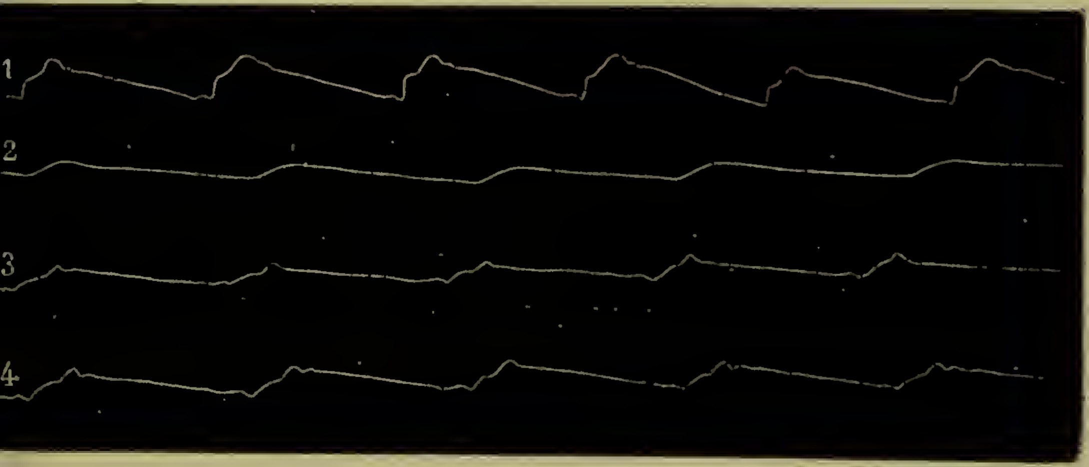
* Dr. G. A. Buckmaster, Lecturer on Physiology at St. George's Hospital, will kindly join the Author in these and other time-determinations.

CHAPTER XI.

THE ANASTOMOTIC PULSE TRACING. FURTHER OBSERVATIONS.

It is to be regretted that the foregoing conclusions should have been based upon the observations of a single case. Fortunately Marey's tracings (*loc. cit.* pp. 624-629) afford some confirmation to our results.

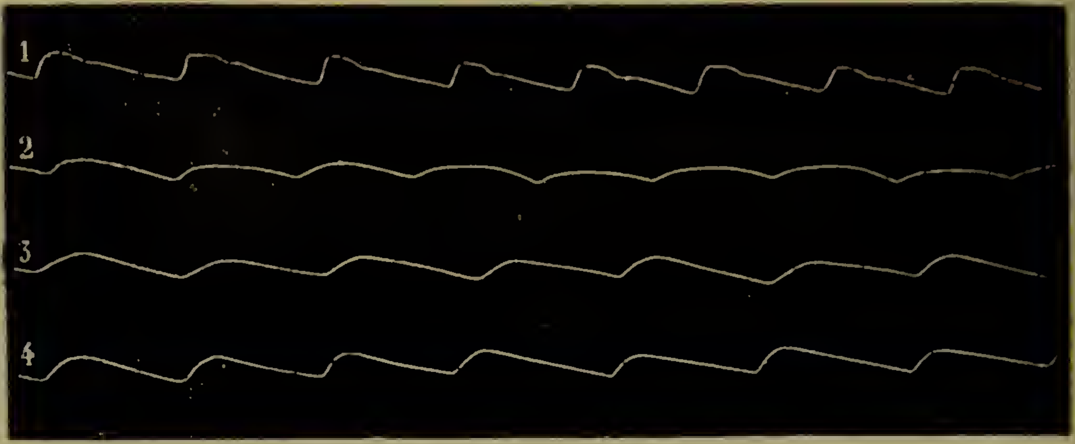
Fig. 156.



Gradual return of arterial pressure in the carotid of a horse after ligature. 1. Carotid pulse before deligation. 2, 3, and 4. Tracings of the anastomotic pulse beyond the ligature, taken at successive moments after deligation. (Marey, *loc. cit.* p. 624.)

The tracings taken from the carotid of a horse, below the ligature, present in a marked degree increased obliquity of the line of ascent, with relatively sustained tension during the later phases of the wave. The slowness of the systolic rise is yet more striking in the radial tracings from man, taken some days after ligature of the brachial; but, owing to the very different channel of anastomosis in a case of that kind, the other features of our anastomotic pulse-tracing are conspicuously absent.

Fig. 157.

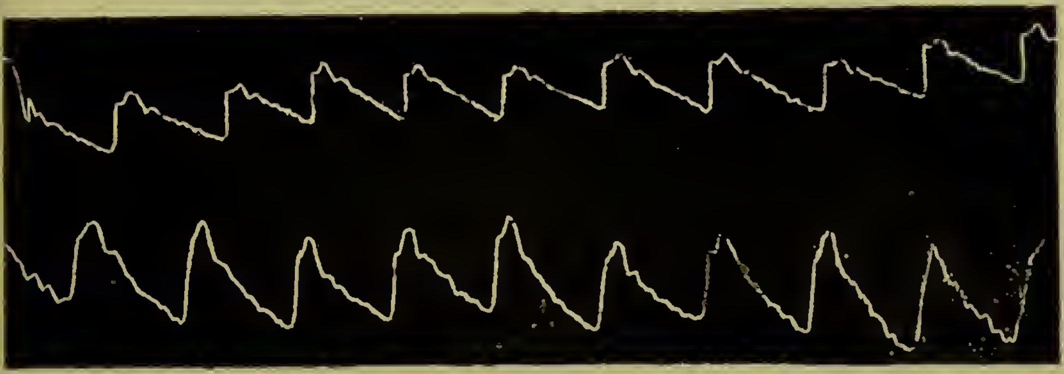


Gradual restoration of radial pulsation after ligature of the brachial artery, in man. 1. Radial pulse from the sound side. 2. Anastomotic pulse eight days after operation; 3. eleven days, and 4. seventeen days after operation. (Marey, *loc. cit.* p. 628.)

Since the foregoing remarks were written radial tracings were taken from a man, *æt.* 40, a printer, the subject of Granular Kidney. The wave in his pulse was large and lasting. Its compression was not difficult; but pulsation persisted beyond the compressing finger, affording proof of a strong anastomotic circulation. Fig. 158 shows the natural pulse-tracing, as well as that taken below the block, after applying to the artery considerable pressure.

The same forcible pressure was employed in obtaining the tracing of the pulsation above the block, from the same patient's left wrist.

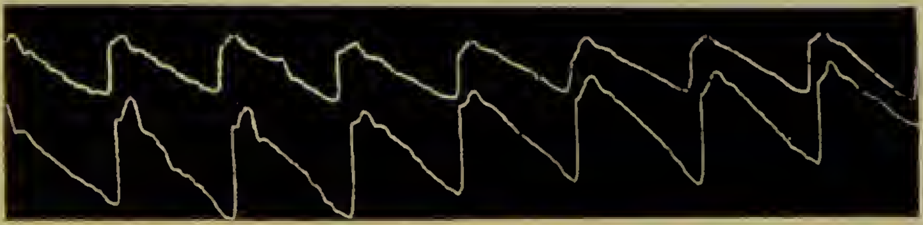
FIG. 158.



The ordinary and the anastomotic pulse in a case of granular kidney. The upper tracing is that of the ordinary rt.-radial pulse; the lower tracing was taken immediately afterwards, ½ **inch below the blocking finger.** Pressure throughout: 200 grms.

In this second case, the anastomotic pulse-tracing and that of the pulsation above the block were each taken immediately after a sphygmogram of the unmodified direct pulse, and on the same slip as the

FIG. 159.



The ordinary pulse, and the pulse above the block, in the same case as above. The upper line is the tracing from the left radial pulse, before interference. The other sphygmogram was taken immediately afterwards ½ **inch above the blocking finger.** Same pressure in both instances.

latter. The steadiness of the pulse-rate adds also to the facility thus obtained for an analysis of the results of obliteration. These results differ widely from those recorded in the first case. The reason for this difference probably resides in the essential difference in the character of the unmodified pulse in the two patients, one of them presenting markedly sustained pulse-tension, the other, absence of tension. A systematic study of a series of sphygmograms of the blocked pulses in the various types of pulse is clearly called for before definite conclusions can be framed.*

Leaving, for the present, out of consideration the vibratile character of the tracings, which may perhaps have been due to muscular tremor communicated from the blocking finger forcibly applied to the artery, we find in this second set of tracings the following peculiarities.

(1) The most striking feature is one which we notice in both varieties of the blocked pulse, viz., the large size of the waves, as compared with those of the ordinary pulse, traced under identical pressure from the sphygmograph. This increased amplitude is only slightly less pronounced in the anastomotic tracing than in that taken on the proximal side of the block.

(2) In both tracings also the details of the wave are less obscured than in the ordinary pulse-tracing; and again in this respect the pulse-record taken above the block is the more telling of the two.

(3) The anacrotic feature in particular stands out more clearly than in the ordinary pulse-curve. Specially noticeable is the greater elevation of the

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* Dr. Cyril Ogle has kindly undertaken this investigation, which will probably yield interesting results.

summit of the wave above the anacrotic notch. In the ordinary pulse-tracing the summit resembles a depressed plateau much more than an apex.

(4) The dicrotic notch and rise are unfortunately difficult to identify in any of the tracings. In this respect the modified pulses resemble closely the ordinary pulse.

(5) Lastly, the modified pulses agree with the ordinary pulse in presenting the usual features of sustained tension.

For the increased size of the pulsations above the block, an explanation, which we have reproduced in these pages, was long ago suggested by Marey. It is consistent to assume that the same mechanism holds good in the case of the anastomotic pulse whenever the size of the latter almost equals, as in the present subject, that of the direct pulse.

CHAPTER XII.

THE ANASTOMOTIC CONDITIONS CONSIDERED IN THE ABSENCE OF ANY INTERFERENCE. THE ANASTOMOTIC CIRCULATION IN ITS RELATION TO THE DIRECT CIRCULATION.

THIS subject is one almost exclusively for speculation, since neither the finger nor the sphygmograph can be employed for its study. Nevertheless, in the preceding chapters materials are supplied which may help us at least to frame a notion of the intra-arterial events occurring beyond the reach of touch, and of sight.

The two elements of the pulse, blood-stream and blood-wave, need to be separately considered.

1. The Arterial Current.

Hitherto, for convenience of study, we have isolated and made prominent the anastomotic pulse by blocking off the main pulse at *Cf.* As soon as the blocking finger is removed, the direct radial stream is set up again, its force being so far superior as to prevent the occurrence of either stagnation or reflux within the radial artery. Its passage, however, is

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contested, and a varying proportion of its systolic force and velocity must be absorbed in the struggle. Had there been no anastomotic circulation, the direct current would, *cæteris paribus*, have acquired greater rapidity than it now possesses. We may then attribute to the anastomotic circulation at least one modification of the direct radial blood-stream, namely, loss of velocity—an identical effect being of course produced in the ulnar artery supplying the anastomosis.

2. The Pulse-Wave.

Whilst the velocities of the two waves are also opposed and tend to neutralise one another, their pressures on the contrary combine and add up to a greater pressure than that individually possessed by either.

Inasmuch as the two waves are nearly synchronous, the increase in pressure will be greatest at or near the summit of the wave and least at its foot. The alteration in pressure will therefore be proportionate in size to, and will nearly coincide in time with, the pulse-wave at the wrist. During the intervals between waves we shall expect to find no departure from the normal. In that respect we notice a great difference between the pressure effects due to the anastomotic wave, which are intermittent, and those due to the capillary peripheral resistance and to the anastomotic blood-column, which are continuous.

On the other hand, inasmuch as at any spot in the radial, or, as the case may be, in the ulnar artery, the anastomotic wave arrives a little later than the main wave, there might be at each spot a double crest;

and during the interval between the crests (which would last longer the higher in the artery the observation is made) pressure would be kept at a high level.

FIG. 160.

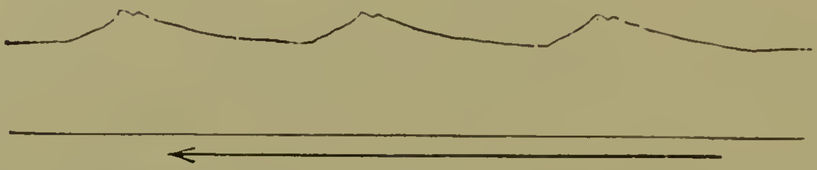


Diagram of pulse tracing, showing double crested summits, such as might be produced by the direct and the anastomotic wave.

Thus the wave-summit might be modified in its duration, which would increase proportionately to the distance from the periphery, and in its strength, which would tend to grow in proportion to the size of the original wave.

The Relations of the Anastomotic Condition to the Peripheral Circulation.

What influence may be felt by the general circulation of the part is a still more obscure question than that relating to the intra-arterial events in the radial and in the ulnar arteries.

In the first place, is the condition in question part of the normal state, at least in some individuals? The different sizes attained in different subjects by the *Superficialis Volæ* artery suggest this possibility. In many subjects, and probably in the greater number, it may be shown that the condition is a passing one, and a question arises as to its significance and as to its results whilst it lasts.

Limiting ourselves to the cases of occasional anastomotic pulse, we are not sure that the condition is special to the radial and ulnar arteries. There is reason to believe that it is shared by other arteries accessible to the touch. Probably a transmission of the wave is most likely to take place from one artery into the other whenever the arterial system in general is relaxed, the *Superficialis Volæ* then sharing in the general increase in calibre. This is often observed in the large, quick pulse of fever. The presence of a moist surface, of capillary pulsation, and of dicrotism sufficiently indicates that the same relaxation prevails in the superficial arteries and in the capillaries also.

The anastomotic pulse may, however, occur under wholly different circumstances, the intercommunicating arteries then widening their channel, not as part of a general vascular relaxation, but owing to generalised constriction of vessels of smaller size. As the arterioles shut off by their contraction much of the capillary outflow, there is a local arterial overfilling. In this case, instead of an increased volume of the cardiac wave, and of an open way through the peripheral channels, increase in peripheral resistance is the apparent cause.

The Influence on the Pulse and on the Ictus.

The pulse, assuming, notwithstanding previous remarks, that it can be felt lightly without interfering with its intra-arterial factors, will be found greatly to differ in these two opposed conditions: large and relatively soft in the one, small and relatively hard in the other; the tension in the first evanescent, in the second long sustained. In one particular, however, both pulse-types will agree, namely—the strength of the ictus. The mechanism of the ictus is modified by the anastomotic pulse in a very definite manner. So long as no large anastomoses exist, the rebound takes place at the periphery; but with the opening up of a shorter circuit the site of rebound is moved nearer the heart, and the result is analogous to that of intercepting the wave at the wrist with the finger. A special feature of variation and of suddenness arises from the direct conflict and summation of the two opposed headlong waves, followed in due course by the rebound from the periphery. This partly explains the slapping, forcible character of the ictus in febrile dicrotism, where an anastomotic pulse and a capillary pulse are seldom absent. In conclusion, the pulse must be so much modified that it should become possible, with advancing experience, to tell the presence of the anastomotic condition by ordinary palpation, without resorting to the special test.

The Influence on the Peripheral Circulation.

Whether the capillaries beyond the anastomosis be freely patent, or whether they be constricted, they must feel the influence of a modified systolic shock.

Whilst deadening velocity, the conflict between the opposing waves must locally raise the pressure of the beat. If the arterioles and capillaries be constricted, much of this pressure would simply recoil from them, the arterial pulse being kept thereby tense for a longer time. In the opposite condition of arteriolar relaxation the increased pressure would find free vent through the capillary system, though perhaps with slightly lessened velocity. Capillary pulsation would be increased, and perhaps set up if previously absent; whilst the artery, owing to the rapidity of the ventricular output noticed in these conditions, would lose pressure and tension early in the wave, and a dicrotic rise would subsequently occur.

It would be interesting to study how closely the anastomotic pulse and dicrotism may be bound up together, and to what extent their relations may be of a causal kind.

Many other questions remain unmentioned. Indeed, this brief sketch cannot pretend to contain more than elementary suggestions for future students.

CHAPTER XIII.

TACTILE THRILLS.

The calibre of normal arteries is so accurately regulated by the volume of the contents that every part of the vessels and of their branches is kept full. There is not any room left for eddies such as are apt to occur in saccular aneurysms; nor are there any abrupt inequalities of space and of pressure such as may obtain in cirsoid aneurysm and in aneurysmal varix.

By the pressure of the observer's finger the normal balance is more or less altered locally, but the necessary conditions for the production of a thrill are not set up in most cases. Though its calibre is diminished, the artery remains full both above and below the narrowed portion of its channel.

Thrills in thin tubes, leaving aside any tremulous movements (see von Kries, p. 47), imparted to the tube-walls from without, may in individual cases probably depend upon one of the following modes of origin:

(1) The passage of a current of blood from a constricted into a wider channel;

(2) The mutual interference or conflict of two opposed currents meeting straight or at an angle.

(3) Whether mere waves of pressure, meeting from opposite directions, are competent, independently of any change in the direction of the flow, to set up by their mutual interference any perceptible thrill is a question which the writer is not able to discuss. Local conditions of this kind are to be found in the circulation; but in each case it is possible to attribute the thrill observed to the agency described under (1).

Provisionally, then, we need only consider two kinds of thrill: those produced by eddies in a stream flowing in one and the same direction, but through channels of uneven diameter; and those set up by the conflict of directly opposed currents, or by the confluence of currents meeting at an angle.

Thrills produced as a Result of Vascular Constriction.

Familiar instances of this variety are the venous thrills in the neck, and the thrill which is set up in the carotid by awkward postures in recumbency. The same mechanism explains the common thrills observed in arterio-venous communications and in many arterial aneurysms, at the moment of their systolic filling and of their diastolic emptying. Again, valvular cardiac thrills are accounted for in the same way.

The Arterial Thrills at the Wrist.

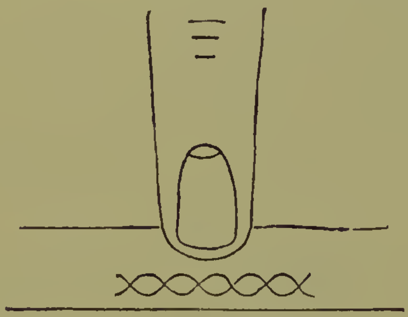
But we are mainly interested in the thrills at the wrist. They are occasionally felt in two situations: close to the bend of the wrist—and in the hollow of the wrist, over the usual site of palpation for the radial pulse.

The *thrill at the end of the wrist* is felt in some subjects as it were spontaneously; but it may be lost and then difficult to find again. This circumstance had led the writer to imagine that it might be due to wave-interference, between the later phases of the systolic wave and the rebound-waves, which arise not only from the continuation of the radial itself, but also from the *Superficialis Volæ.* It is indeed conceivable that the minute want of synchronism between these two rebounds may alone explain the thrill, altogether independently of the systolic wave. The first supposition is, however favoured by the circumstance that a thrill is often obtained higher up, in the hollow of the wrist, where no important rebounds meet. But, as previously stated, the author is unable to give any proof of the possibility of thrills arising from mere conflict between waves, even when the damping effect of vascular tension is removed, and even when the conflicting waves possess different velocities and pressure; and he prefers to regard this as another instance of the effect of pressure and vascular constriction, in this case assisted or complicated by the immediate vicinity of a bony surface.

The *thrill at the hollow of the wrist* is less erratic, and can be readily obtained again, in any subject presenting it, by a careful accommodation of the pressure of the finger. The degree of pressure needed in each case lies somewhere between ii and iv, usually nearer iv than ii; that is, the artery needs to be considerably narrowed.

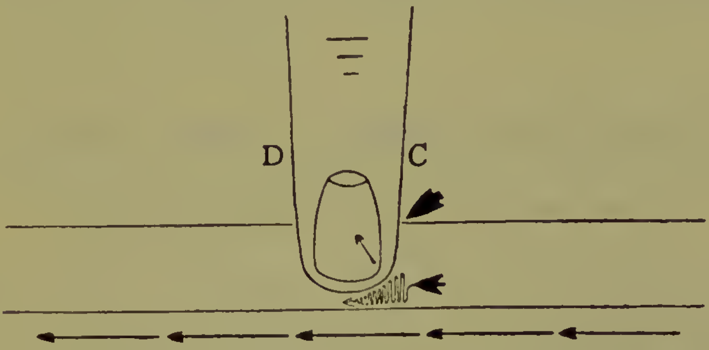
It is sometimes possible to distinguish two thrills, differing in their site as well as in the pressure producing them. One of them extends under the entire width of the pulp, and is produced by that degree of pressure which elicits the intermediate ictus. The other needs a higher pressure, verging upon pressure iv, and the thrill becomes localised to the small arterial wedge still remaining patent under the proximal side of the finger.

FIG. 161.



Thrill felt by the entire finger surface in contact with the artery—(usually with pressure iii).

FIG. 162.

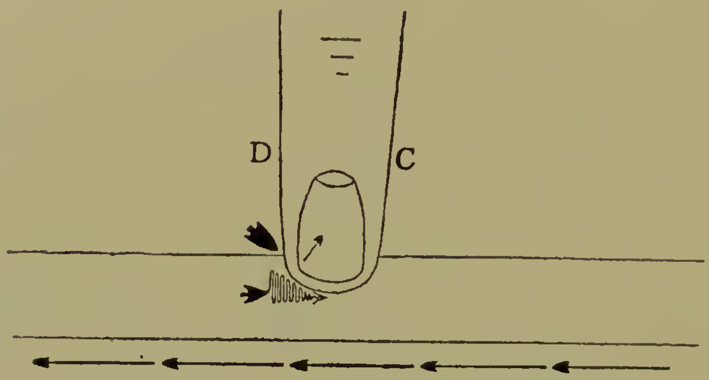


Thrill limited to proximal half of finger-tip—under pressure iv.

It must not be concluded that the radial thrill can only be obtained with pressure iii. Sometimes it may be felt with pressure ii; it is then localised under the distal half of the finger-pulp (see Fig. 163).

In all these cases the thrill is systolic and precedes the ictus. This gives us a ready means of demonstrating the existence of the wave-period anterior to the pulse-beat, which is so easily overlooked, and which in the sphygmogram occupies so brief an interval.

FIG. 163.



Thrill occasionally limited to distal half of finger-tip—under pressure ii.

Under the finger the fine and rapid thrill seems to multiply the time, and lends apparent duration as well as prominence to this neglected section of the wave.

The Mechanism of the Thrill.

The Part Played by the Finger.

The conditions leading to thrill are partly supplied by the pulse, partly by the finger applied to it.

The part played by the finger needs some explanation. When a live fly is placed in an inflated paper bag, the noise which it produces is not necessarily accompanied with thrill. If the paper bag be gradually flattened so as to confine the fly to one corner, thrill will be set up, and its pitch will seem to increase as the space is narrowed.

When the finger is applied with pressure ii (see p. 97), a fairly wide channel is left for the further progress of the systolic wave. When the pressure is increased to iv, the arterial channel is considerably reduced or even blocked, and with pressure v it is absolutely obliterated. Pressure iii, the only one which enables us to feel in each pulsation the systolic wave and its rebound (although both waves are reduced, and chiefly of course the back-wave), supplies the conditions most nearly approaching those suggested by the instance of the fly. The superficial and the deep parietes of the flattened vessel are so closely approximated by the pressure of the finger as to be set into vibration by the oscillations of their contents, and the vibration is communicated to the finger itself. The oscillations are not spontaneous as in the rough simile we have given. Their origin is probably always artificial. As to the mechanism of their production a few suggestions may be offered.

The Intra-Arterial Conditions Leading to Thrill.

The thrilling pulse (*pulsus vibratus*, *tremulus*, *serratus*, &c.) was perhaps better known to ancient physicians and to those of the past century than to our contemporaries. The prevalence of heroic bleeding may have formerly caused it to be more frequent. It may also be that we read and hear less about thrills, because, not being readily taken up by the sphygmograph, they have not found a place in sphygmographic nomenclature, and have dropped out of notice.

Dr. Sansom, however, gives in his valuable book * a tracing of a pulse showing multiple vibrations from a boy the subject of hæmophilia. "When the serrations are not due to muscular tremor, they arise from vibrations of the wall of the artery itself. They may occur when the tension is low, but they are also frequently manifested in the sphygmograms of prolonged tension."

The correctness of the current impression that thrill in the pulse is indicative of low tension and of deficient volume and strength of the wave, can hardly be put in question. Suitable manipulations, by which the blood-supply to the artery under observation can be diminished at will, afford demonstration on this point. The *first requisite* in producing a factitious thrill in a normal pulse is *to lessen its contents.* The *second requisite* is to feel for the thrill with *a sufficiently light finger-pressure.*

We may from this infer that the mechanism of thrill is *the vibration, in a partly collapsed artery, of a much reduced blood-stream, as it passes points where the light pressure has produced close approximation of the opposed sides of the artery.*

Since the vibration would occur on either side of the constriction, this explanation applies to the apparently diverging cases of the thrills felt at the site of the proximal and of the distal ictus, as well as to the thrill felt with pressure iii under the middle of the pulp.

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* "The Diagnosis of Diseases of the Heart and Thoracic Aorta." By A. Ernest Sansom, M.D., F.R.C.P. Lond. Griffin & Co., 1892.

As with the mighty thrill of a flapping sail, the first essential is a relaxation of the membrane, and this is brought about by relative emptiness of the artery. A simple means of carrying out this condition will be pointed out in connection with the influence of attitude on the pulse (see p. 406).

Thrills Produced by Conflict or Confluence of Currents.

The occurrence of thrills in circumstances of this kind is familiar to us in aneurysmal varix and varicose aneurysm, and in various other instances outside the body. The thrill of arterio-venous intercommunications is peculiarly instructive in respect of the difference in tension and in blood-pressure existing in the two vessels. In the relative looseness of the venous membrane we recognise the factor which has been discussed above.

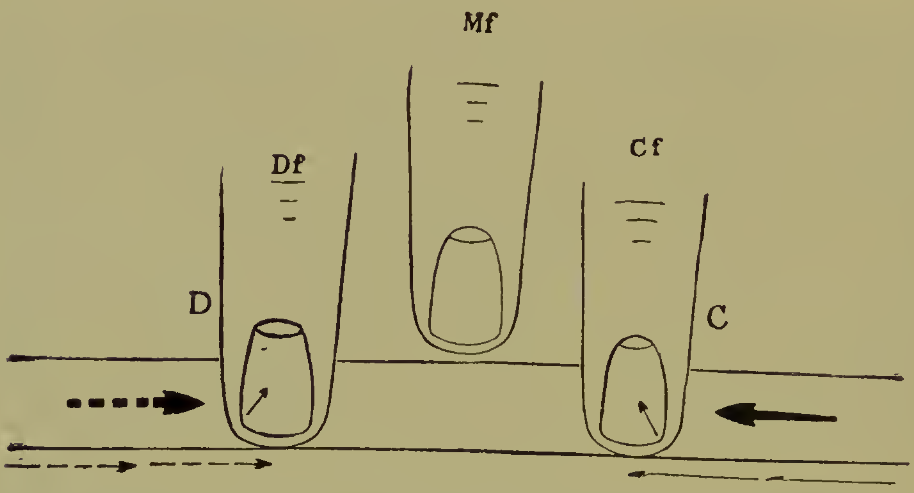
A perfect instance of conflict of currents is supplied by the anastomotic pulse, in which thrill might almost, *à priori*, have been expected. It was in connection with an experiment on the anastomotic pulse that this probability first occurred to the author. A thrill, however, was not to be found in the absence of favouring circumstances.

Experiment XL.

If the pulse be felt in the ordinary way in a subject presenting an anastomotic wave, no thrill will be detected. The pulse-pressure and the vascular tension are too high, owing to the double supply of blood and of pressure. The arterial walls are too much on the stretch to respond to any fluid vibration of their contents. They need first to be relaxed, and the blood-stream to be reduced.

An easy method is to grasp the upper wrist from the radial side with both hands, with thumbs in apposition under the arm, and to place both ring fingers on the artery. These may at any moment be pressed down so firmly as to stop both waves; or simultaneously relaxed; or, lastly, relaxed alternately. Meanwhile the effect is watched by one of the index fingers (or by both) applied to the artery. The extent to which an even moderate relaxation of the obliterating pressure sends up the volume and strength of the returning pulse will be at once noticed on trial. It is therefore necessary to raise the compressing fingers very gradually until a point is reached when a feeble pulse is felt, and with it a

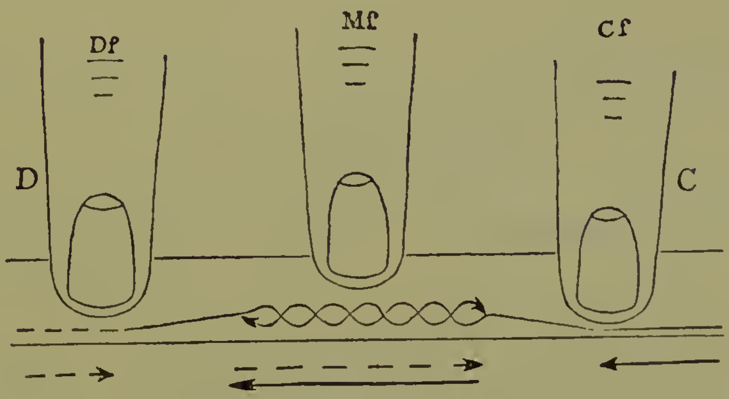
FIG. 164.



Position of the observer's fingers previous to the experiment. Both ring-fingers, *Cf* and *Df*, control the size of the artery, whilst the fore-finger *Mf* feels for the thrill.

thrill. This thrill has appeared to the author to be the product of both currents; but on this point it would be rash to speak positively, since almost precisely analogous conditions lead to a thrill in the cases free from anastomotic complication, which we have described above. The whole subject is one needing much study.

FIG. 165.



Showing how the direct and the anastomotic currents, reduced and equalised by suitable pressures, may set up a thrill by their conflict.

CHAPTER XIV.

DICROTISM AND ITS FACTORS.

A *tactile* study of dicrotism cannot be included in these pages, the author not having reached this difficult stage in the tactile analysis of the pulse. His only contribution to the subject are observations of a mixed tactile and sphygmographic character concerning the moment of the dicrotic wave (see p. 395). Nevertheless, he would venture a few criticisms and suggestions which arise out of the studies detailed in previous chapters.

"Dicrotism" not being bound up with any structural defects, the resemblances between the normal and the "dicrotic" wave should be at least as great as their differences, and there should be mutual help in the study of the two waves, the constituents of which are the same, the proportions only being altered. Theories which introduce new factors, or suppress those belonging to the normal pulse, would lose thereby some of our confidence. Thus, the dicrotic wave is probably best studied in the "dicrotic" tracings, where it stands strictly isolated, by a clear interval, from the primary wave: diminish the rise and the interval, and the normal tracing should be restored. Conversely we should endeavour to imagine under the normal tracing the outlines of a primary wave, of a deep depression, and of a great secondary rise.

THE PECULIARITIES OF THE DICROTIC PULSE.

An enumeration of the peculiarities connected with the "dicrotic pulse" will facilitate our study. Among them we notice :

(1) Frequency of heart beat ;
(2) Rather rapid systole—in other words, early sigmoid closure ;
(3) Relatively great initial energy ;
(4) Early and great fall of pressure ;
(5) Considerable subsequent rise of pressure ;
(6) The skin usually warm and often moist ;
(7) Capillary pulsation usually to be detected.

And on close inspection of tracings we observe the following sphygmographic features :

(8) Steep ascent to a single apex ;
(9) Rapid and deep fall to the base line, without predicrotic wave ;
(10) More or less broad trough, contrasting with the sharp primary summit ;
(11) The dicrotic ascent is oblique and curved, or even may have a faint angular projection ;
(12) The dicrotic apex is blunt and broad, and its fall is more oblique than that of the primary wave ;
(13) It occurs late in the sphygmogram, and its delay increases with the frequency of the pulse.

THE REGIONS OF PERIPHERAL AND OF CENTRAL REBOUND IN THE TRACING.

We may hypothetically consider two regions in the sphygmogram. The earlier one, down to the dicrotic trough, would contain not only the primary cardiac wave or waves, but also the early peripheral rebounds, both of the descending (centrifugal) and of the ascending variety. The later period would include the large central rebound or dicrotic wave, and also any later peripheral rebounds such as described by von Frey as rebound waves of the second and third order.

Obviously the first of these periods in the tracing belongs as it were to the vessel under observation. Descending peripheral rebounds from other vessels would be included, but, we may disregard them, since, at this stage, even the much larger cardiac wave leads to no visible back wave.

On the contrary, the second period of the tracing registers events occurring at a distance, as well as local ones.

In "dicrotic" tracings the earlier period is one of absolute smoothness, as in tracings from aortic regurgitation; but, from the latter they differ in preserving the same smoothness to the bottom of the dicrotic notch. No peripheral rebounds are visible. Whether the rebounds are absent, or latent only, we shall consider later on.

THE PERIPHERAL FACTORS, RESISTANCE AND ELASTICITY; AND THE ARTERIAL ELASTIC REACTION.

The Dicrotic Wave in the Normal, and in the "Dicrotic" Tracing.

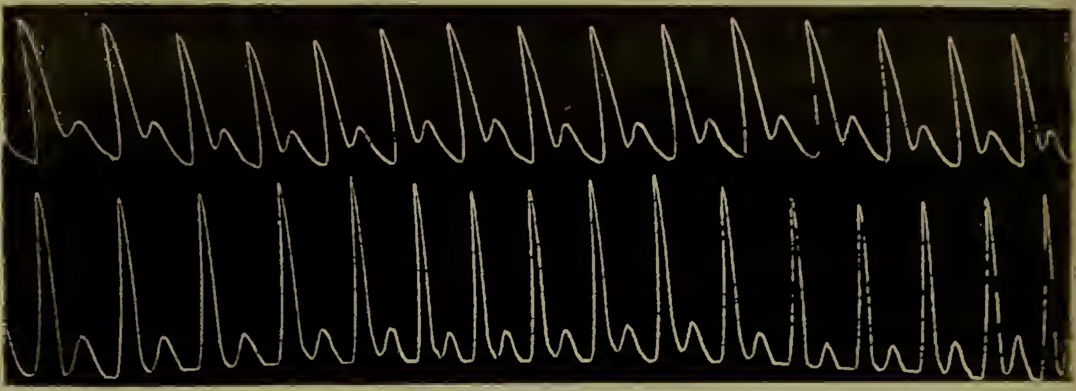
With diminishing peripheral resistances we might expect to find shorter elastic reactions—*i.e.*, a quicker stretch and a quicker recoil of the aorta and arteries. Supposing the periphery offered *no* resistance, but a steadily widening lumen, then a single oscillation of the arteries would rapidly dispose of each systolic injection. The normal pulse-trace shows, however, that there is a sustained resistance. Though the duration of systole be only a fraction of the time, the pulse-wave, both in aortic and in radial tracings, occupies the whole time between beats. The base line is not reached until the moment when the next rise is about to set in.

In the "dicrotous" pulse this fulfilment occurs very soon after the end of the short systole. The base line is reached at one drop, and we may for the present assume that the blood-wave has passed beyond the radial sphygmograph; for if it had not, how could the lever fall so low?

This fall to the base line would show that, in the "dicrotic" pulse, the dicrotic rise is always independent of the primary wave; not one compounded, as in the healthy tracing, of the remainder of the primary wave + the superadded dicrotic wave.

In other words, the dilating capillaries would absorb the wave to such an extent that its fall would be rapid and complete; conditions arising whenever the peripheral arterioles are widened, and the capillaries made so pervious as to transmit a systolic impulse as far as the radicles of the veins, especially if the amount of blood propelled be moderate and the force of systole relatively great; in a word, precisely those conditions which we find in the pulses described as fully dicrotic and as hyper-dicrotic.

FIG. 166.



Fully dicrotic pulse tracing (lower line): the notch descends to the base line. The dicrotic wave is isolated from the systolic wave.

Thus, in the fully dicrotic tracing* the primary rise is considerable, but quickly ended. The aortic elastic reaction is prematurely extinct, and should be difficult to resuscitate, short of a fresh outflow from the ventricle. Nevertheless, a second wave of pressure passes under the lever of the sphygmograph. The lever, in the special case of the hyper-dicrotic pulse, has not even time to fall again to the full depth of the dicrotic trough, before it is carried up by the following heart-wave; whilst in the fully

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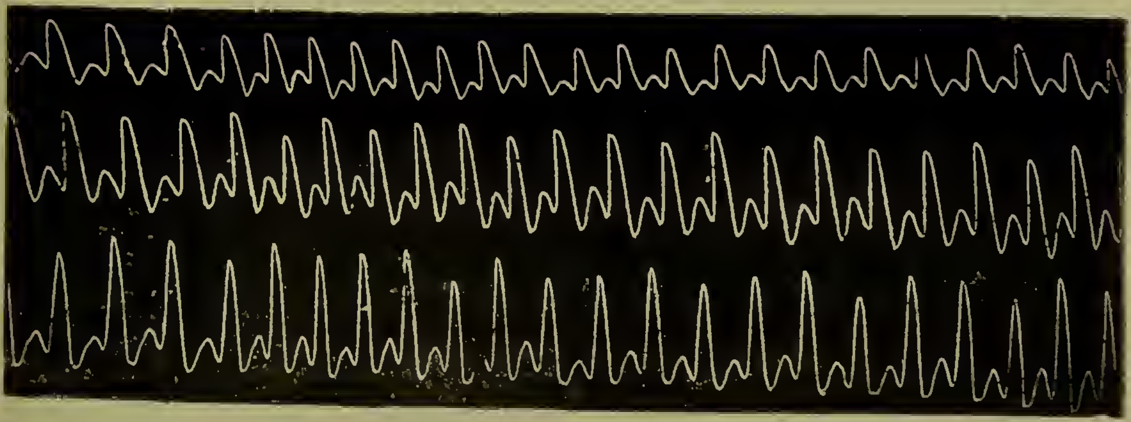
* The same reasoning would apply to the hyper-dicrotic pulse.

"dicrotic" trace it returns to the bottom of the trough before being lifted again by the next pulsation.

FIG. 167.



Hyper-dicrotic pulse. Deep level reached by the notch. The dicrotic wave isolated from the systolic wave, but intercepted in its fall by the subsequent systolic rise.

Since the heart is certainly not responsible for this second rise, we must look for some other pumping force; this must be of the nature of a reflux-wave, occurring after an interval of abeyance of pressure, such as can only be obtained in tubes of great expansibility.

The Site of the Dicrotic Rebound.

The heart has, therefore, no direct share in producing the dicrotic wave. In normal pulses free from capillary pulsation, the rebound is supposed to take place at the entrance of the capillaries. Even here, we must, however, assume that the capillary area is capable of absorbing a portion of the blood and of undergoing slight distension by it, leading to a returning *wave of elasticity*, in addition to the relatively more prominent *wave of rebound.*

Capillary Pulsation, and the Elasticity of the Peripheral Tissues in Relation to it.

In the normal state capillaries show no pulsation, partly because the arterioles are too much narrowed to allow large waves to travel on, partly because their own diameter is so very small as to deaden the wave by friction.

Failing these checks, capillary pulsation occurs: a blood-reservoir far exceeding the capacity of the aorta, is put under systolic tension by the heart-wave. Owing to its great thinness, the capillary wall has not any considerable elastic reaction of its own. The so-called capillary tension and elastic reaction are really in great measure those of the surrounding juices, tissues, membranes, and especially of the skin itself, as may be seen and felt, in these conditions, at the tip of the fingers. The amount of energy stored up at each beat and again set free into the arterial system, will be obviously proportionate to the velocity and amount of the systolic charge, and to the stretch and recoil of the pulsating textures.

By transmitting the systolic wave to the relaxed capillaries, the arterioles have opened up not only a most rapidly receptive and ample reservoir, but one possessing an extraordinary power of recoil, as well as of expansion, differing of course in each subject.

The Venules in Relation to Capillary Pulsation.

This great individual variety might alone explain a divergence in the aspect of tracings; but there are other modifying agents which will largely influence the kind and the amount of dicrotism. Chief among these is the share of the capillary recoil expended on the venous circulation. Observation suggests that this amount may be a very variable one.

Let us consider for a moment the venous boundary of a capillary district. On this, as on the arterial side, although perhaps not to the same extent, there is a large excess of the number of capillaries over that of the venules. Under ordinary circumstances, the latter would be amply supplied by the blood output from the capillaries. Should, however, the capillaries become dilated, relative pressure might be set up within the venules. Now the greater the pressure within the venules, so much the larger will be the recoil occurring into the arterial system. In this case the peripheral resistance has shifted one step beyond the capillaries, to the venules. It is possible, however, to push the argument yet another step (and for this we have some warrant in clinical peculiarities actually observed): we might suppose that at times a contraction of the venules takes place (analogous to that constantly recurring within arterioles), which would influence distally the capillary circulation.

Taking, however, the simple case of dilatation extending to capillaries and venules, as well as to arterioles, the systolic wave under these circumstances (and under these circumstances alone) would have scope to develop itself onwards into the venous system. Normally, this is not possible, the head of the wave striking against the capillaries of the periphery before its hinder extremity has left the heart. It would follow that, if normally the head of the wave had given in the radial tracing any sign of its rebound from the periphery, the radial tracing of the cases in question (capillary pulsation), would give no visible sign of such rebound. If we turn to sphygmograms of fully dicrotic or hyper-dicrotic pulses, we shall verify the apparent absence of a pre-dicrotic rise and fall. Its absence is not, however, an invariable peculiarity of pulsation in the capillaries, though it seems to be a constant feature of the very rapid dicrotic pulses.

The relaxation of both sub-capillary districts, coinciding with that of the capillary district, would throw upon the peripheral soft parts very considerable systolic stress, whilst rapidly absorbing the systolic wave into a widely dilated lumen; conditions exactly suited to produce the features of the dicrotic pulse. Though the blood would pass through at an increased rate, thus keeping up the extremely rapid heart-beat, it would not fail to excite a powerful peri-vascular pressure and elastic reaction. Assuming the latter to be fairly constant in its time, even in different individuals, the strange anomaly of the hyper-dicrotic and of the monocrotic tracings would be more readily explained; the waves racing each other being of very different origin—the one due to the heart, the other to the pulsating tissues at the periphery.

The Rebound-Wave, and the Wave of Elastic Recoil.

The peripheral throbbing (*e.g.*, of the finger-tips) seen in the bearers of a dicrotic pulse, is too marked a vascular condition to fail to leave an unmistakable record. It is, we would suggest, twice registered in the tracing: first, as a great fall of pressure; and, secondly, as the great dicrotic rise; the first accompanying the visible pulsation or stretch of the skin, the second the visible cutaneous recoil; both stretch and recoil being of course understood to belong also to the capillaries and to the tissues of the part. The great elastic oscillation will vary in size according as the capillary sluice is thrown more or less widely open. If much widened, the capillary way will present no obstacle, and will produce no rebound, unless it be a negative rebound, which might well have a share in deepening the predicrotic trough. If, on the contrary, access to the capillaries be much limited, there will be little elastic oscillation, but much wave rebound, of the positive kind.*

Even in spite of arteriolar constriction the capillaries must absorb some portion of the systolic blood, and undergo slight distension by it, leading to a return-wave of elasticity; this is the normal dicrotic wave, much more feeble than that witnessed in "dicrotism," the more obvious event being that of wave-reflection.

This view differs from on older one which localised the elastic reaction in the aortic and in the arterial membrane. Let us repeat that in "dicrotism," this membrane is not long kept under tension. It is on the capillary system that stress is mainly thrown. At the same time we are familiar with powerful aortic throbbings, in particular with the so-called *abdominal pulsations;* these we may probably regard as the counterpart of the dicrotic condition—viz., as the result of capillary constriction (within the visceral area), and of aortic stretching. Investigation of this point might lead to interesting results in the future.

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* This is the combination noticed in typical uncomplicated cases of aortic regurgitation, where the predicrotic wave is relatively the larger one. It cannot be said, however, that in this case the arterioles are contracted, more probably the venules.

CHAPTER XV.

FURTHER ANALYSIS OF THE DICROTIC EVENTS.

On the Absence of a Predicrotic Rise and Fall in "Dicrotic" Tracings.

Does the disappearance of any indication of the predicrotic wave from the smooth descent of the first part of the tracing justify a conclusion that the wave is absent? Some collateral importance attaches to this question. Roy and Adami hold that the wave has disappeared.

In the dicrotic pulse, Roy and Adami find not only a more rapid and deeper drop, but also an earlier one. According to them there is no outflow remainder after the papillary contraction, which is supposed to have expelled the ventricular contents at one jerk; whilst, somewhere in the long drop that follows, fits the time of the sigmoid valve closure. In other words, one of the constituent parts of the pulse-wave has dropped out, as the result of increased rapidity of systole.

This apparent loss of the predicrotic wave, which most tracings confirm,* is an argument for regarding it as produced outside the heart, as a wave of rebound. Had it been a direct product of the heart's contraction, why should it have totally disappeared ?

Viewed merely as an intra-arterial rebound-wave, independent of intra-cardiac pressure, the predicrotic wave could be imagined, without calling to aid so big a postulate, to be open to varied fortunes, even to the point of total eclipse. For it is conceivable that the wave may be not entirely absent, though submerged by some great fall of pressure, or caught up by some great rise coinciding with it. We need hardly look for it at any point in the tracing beyond the region of semilunar closure, since the quick systole of dicrotism would promote its early rather than its late appearance. The predicrotic rise could hardly then lie disguised at the bottom of the broad dicrotic depression, or be included within the dicrotic wave itself. Less improbable is a suggestion that it may, by reason of the rapidity of the events, form some part of the slight width presented by the primary summit in some dicrotic tracings. The majority, however, of the latter culminate in an acute angle rather than in a plateau.

Bearing in mind that at best it can only be a very small wave, owing to its conjunction with large dicrotism, we may provisionally assume that, although it may have been started as in any normal pulse-wave, it has become lost in the great post-systolic fall of pressure which combines with the negative rebound from the dilated capillaries.

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* Some of the hyper-dicrotic pulsations in Fig. 170, p. 398, (after inhalation of amyl nitrite) show an unmistakable predicrotic wave ; and in one or two of them this is preceded by an undulation in the primary downstroke.

The Position Occupied in the Tracing by the Dicrotic Summit; or the Relative Time of the Dicrotic Wave.

Arterial conduction and peripheral delay are the two influences which must tell on the time kept by the wave; and of these the latter presents the more palpable variations, for the capillary pulsation associated with extreme dicrotism has an appreciable duration. The rapidity of arterial conduction also varies (*cf.* p. 200), but in a less important degree, in spite of the much greater distance involved. Thus with an average intra-arterial pressure and velocity the relative time will be regulated mainly by the peripheral factor. If this also should remain unchanged, the position of the dicrotic rise in the tracing will remain constant.

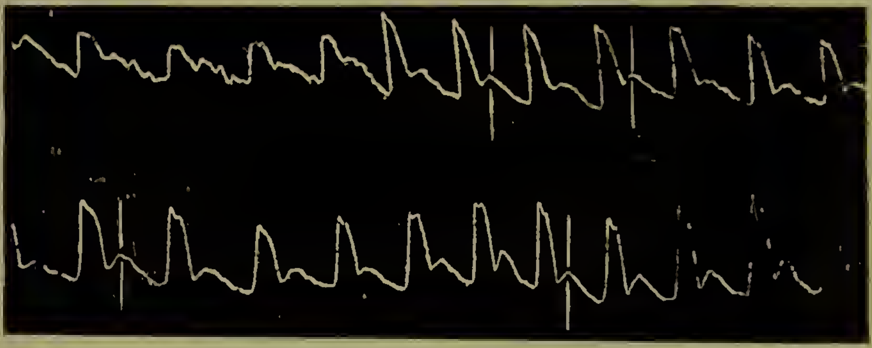
The peripheral delay will be greatly modified if the capillary elastic reaction, instead of being almost suppressed, is brought into full play. The elastic reaction-time seems to be less variable than the rebound-time. At any rate it is not ruled like the latter by the intra-arterial pressure and velocity. Hence if the pulse should quicken, the dicrotic wave need not keep abreast with the systolic wave. It is relatively late, as in the "dicrotic" and "hyper-dicrotic" pulses—it may even be absolutely late, that is, too late to be recorded in the tracing of the pulse-wave, as in the monocrotic variety.

The variations in the dicrotic time under pathological influences will probably become an interesting subject for study. For the present let us merely allude to the respective time differences brought about by obliterating the radial artery above and below the sphygmograph in any normal subject.

Variations in the "Dicrotic Time" in Obliteration of the Artery Above or Below the Sphygmograph.

If it were possible to cut off entirely the partial capillary reaction occurring even with moderately constricted arterioles, the peripheral delay would be much shortened and the dicrotic time made earlier.

Fig. 168.



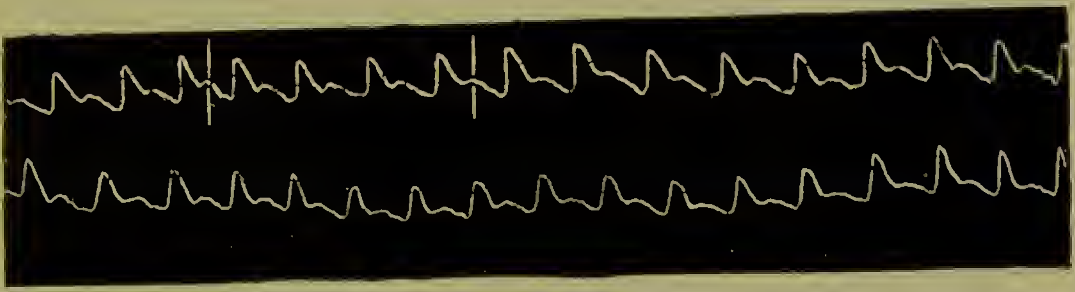
Pulse tracing above the block (same as Fig. 154). The vertical lines point to the apex of the dicrotic wave, enabling the distance of the latter from both ends of the pulse-wave to be measured.

This can be done within the district of the artery under investigation; but, since the dicrotic wave is supposed (see p. 256) to be a sum of peripheral rebounds from the whole body, focussed, as it were, and reflected again by the aorta, so slight a local perturbation could hardly be expected to affect the wave-time. An inspection of the tracings shows, however, that an appreciable difference is made, which will need some explanation. Thus in Marey's tracing (*loc. cit.*, Fig. 159), and in the author's tracing (Fig. 168), both taken above the seat of compression, the results of obliterating the artery seems to have been :

(1) To accelerate the dicrotic summit ;
(2) To narrow and render sharper the dicrotic notch ;
(3) To broaden* the predicrotic portion of the trace, bringing into view one or two predicrotic waves :—results, all of which are opposed to those observed in " dicrotism."

Tracings of the *anastomotic pulse* (Fig. 169), taken immediately below the obliteration, display the same features somewhat toned down.

FIG. 169.



The anastomotic pulse tracing below the block (same as Fig. 153). The vertical lines facilitate a measurement of the distance of the dicrotic summit from the neighbouring upstrokes.

Where is the Centripetal Wave, producing the Dicrotic Wave, to be looked for in the Tracing?

These observations will need confirmation in view of the important conclusions which may be based upon them. If it should be found that the dicrotic time is altered only in the artery compressed, and not in those of the other limbs, this would be almost a proof that the modification in time is due to the local phase of the dicrotic events—that is, to the centripetal wave, which by its reflection (together with other waves) at the root of the aorta, gives rise to the dicrotic wave.

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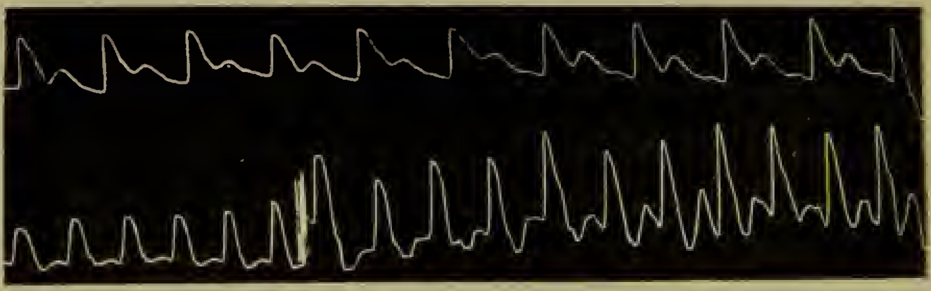
* This is not so well shown in Marey's tracing.

The direction of the dicrotic wave being centrifugal, where is the centripetal elastic wave of which it is the rebound ?

There is nothing inconsistent in the assumption that the dicrotic rise contains not only the centrifugal wave rebounding from the aortic valves, but also the centripetal elastic rebound-wave. Since there is room in the primary wave for the systolic wave and for its rebound also, we shall see that, *à fortiori*, there should be room for a double wave in the dicrotic elevation.

Since writing these pages, I have been favoured by my able clinical clerk, Mr. H. P. Turnbull, with the annexed tracings of the normal pulse, and of its serial modifications under the influence of nitrite of amyl (*cf.* p. 260). The dicrotic wave,

FIG. 170.

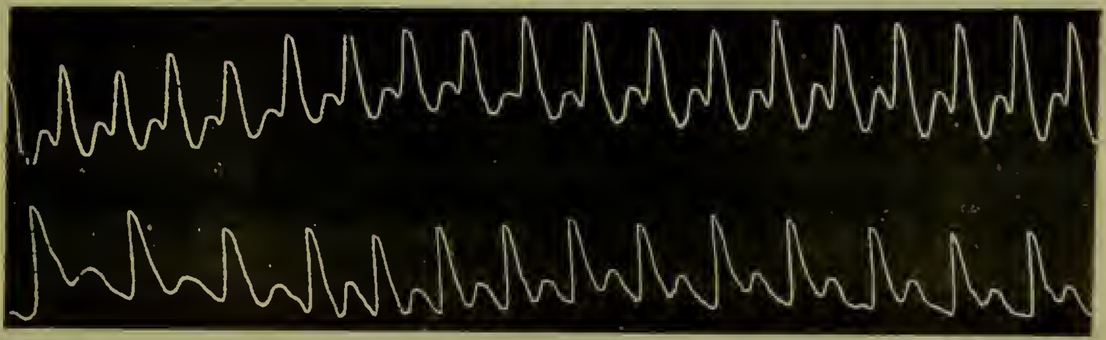


Upper tracing taken before, lower tracing after, the inhalation of amyl nitrite. Pressure: 100 grms. (Marey's Sphygmograph).

after a temporary depression, becomes once more prominent, and rather quickly passes into a hyper-dicrotic stage.

Some of the dicrotic waves present a double crest or a secondary wave; a feature less apparent in the strongly hyper-dicrotic pulsations in Fig. 171, which also lack the pre-dicrotic wave previously visible.

FIG. 171.



Hyper-dicrotic stage continued. Gradual return to the normal type after a period of simple dicrotism.

The last tracing shows simple dicrotism, the dicrotic summit becoming less and less late, until it almost regains its normal position.

Some Suggestive Features of the Dicrotic Wave and Notch.

(1) A first point worthy of notice is the much greater proportion of space occupied by the dicrotic trough and rise in the dicrotic pulse than in the healthy one ; and,

(2) In particular, the duration as well as the depth of the trough. In sphygmograms taken under sufficient pressure to bring out the full height of the primary wave, it is seen that the dicrotic notch at the basal line is appreciably broader than the summit of the primary wave. Moreover, it can be shown* that

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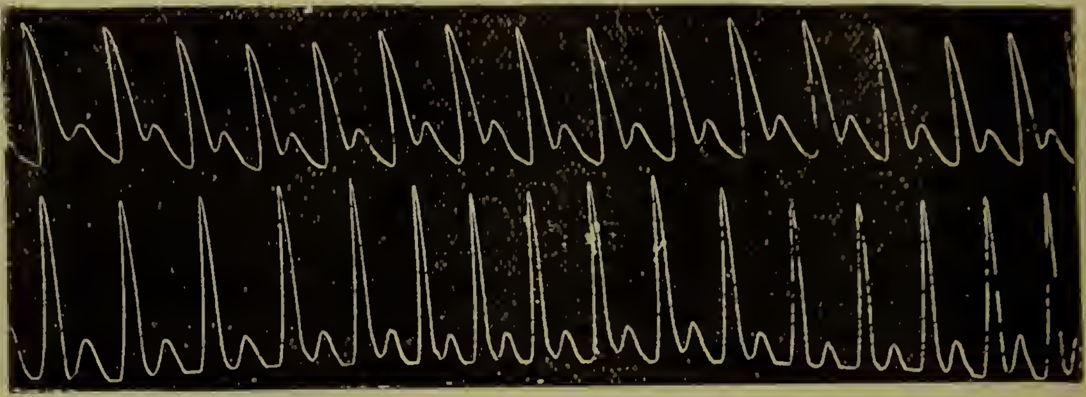
* A horizontal line drawn through the dicrotic summits will show that the notch is, in some cases, at least as broad at this level as the primary wave, sometimes even broader.

the passage of the wave has been followed by an interval not less than its own length ; and that, therefore, the systolic wave proper has passed away, and with it the primary or immediate peripheral rebound-wave.

FIG. 172.



Dicrotic tracing, showing the obliquity and anacrotism of the dicrotic rise, and the bluntness and width of the dicrotic wave.

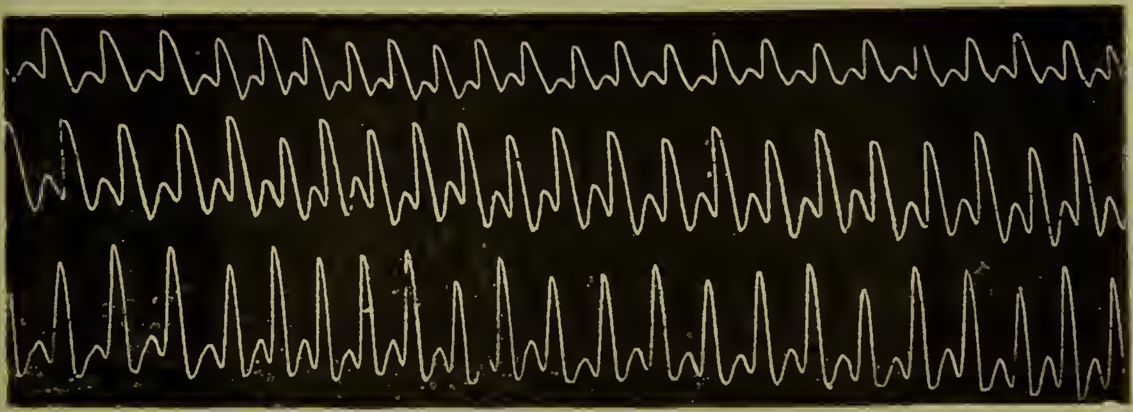
(3) The fully dicrotic wave starting from the base line shows an important peculiarity. Its rise is not parallel with the primary, but more or less strongly inclined away from it, in some cases very strongly so.

(4) Moreover, it is in some instances visibly anacrotic ; and, in many "dicrotic" tracings, more or less rounded at its summit (this bluntness is also a common feature of the minute normal dicrotic wave). The fall of the wave is likewise less abrupt than that of the primary, and in this respect approaches the type of fall of the normal wave.

(5) Not only is the dicrotic summit often broader than the primary summit, but in many a "dicrotic" trace the width of the dicrotic wave exceeds at its foot that of the primary wave.

These peculiarities are not incompatible with a view that the great dicrotic wave is made up of a series of waves, the first of which would be the "local" rebound from the capillary district of the artery sphygmographed. The slight rise initiated by this would be added to by similar rebounds from neighbouring districts. These rebounds, likewise centripetal in their main direction, would reach the aorta in rapid succession, and be reflected as the broad wave, the direction of which has been proved by the tachograph to be centrifugal.

Fig. 173.



Hyper-dicrotic tracing, showing features analogous to those seen in Fig. 171.

According to this interpretation, the centripetal wave contributed by each artery would start the dicrotic wave in that artery; and in each artery the start would be earlier or later according to circumstances; but the body of the wave would be, practically speaking, the same in all arteries, *mutatis mutandis.*

The anacrotic character of some dicrotic waves is also rendered intelligible. Lastly, there would be a general similarity between the primary and the secondary wave; but in the latter the bigger event, that originating centrally, would come last, instead of forming the first part of the rise, as in the systolic wave. The dicrotic wave would be, as it were, the "mirror-image" of the primary wave.

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CHAPTER XVI.

EXPERIMENTAL STUDY OF THE CHANGES IN THE PULSE DUE TO RAISING THE ARM.

THE theories to which this apparently trivial experiment has given rise cannot be profitably discussed before its conditions are better defined.

The quotation from Marey[*] (see p. 166), as well as the descriptions given by other authors, simply mention "raising the arm," but make no reference to the way in which this is to be done, whether actively or passively, moderately, or to an extreme extent, with rigid or with loose elbow. Yet the difference in the results justifies these distinctions.

The Peculiarities Observed, and their Alleged Causes.

Nevertheless observers are agreed as to the chief effects produced on the pulse by raising the arm. These consist mainly:

(1) Of a diminished tension of the pulse;
(2) Of an increased size of its oscillations;

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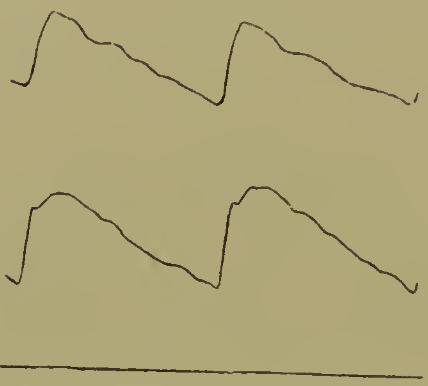
[*] Marey, *loc. cit.*, p. 287.

(3) Of an anacrotic type of its tracing;
(4) Of a reduction in the size of its dicrotic wave.

FIG. 174.



Radial tracings reproduced from von Frey (*loc. cit.*, p. 220). The upper tracing taken with arm dependent; the lower tracing with arm raised.

We may therefore assume that the conditions of their experiments were fairly even, and probably not of an extreme type.

The *loss of tension*, which renders the oscillations larger, but at the same time exposes them to the risk of being completely extinguished by too great a pressure of the finger, are admitted to be due to the draining away of blood from the capillaries, and to the diminished size and comparative emptiness of the latter, whilst the arteries are free from any muscular spasm, and react readily by means of their elasticity to every variation of their contents.

The *anacrotism* is not dwelt upon by Marey. Inasmuch as he speaks of the variation in pressure being abrupt, it would almost seem as though he had failed to elicit this important character in the pulse. We shall see presently that it is inseparable from the other events when the arm is sufficiently raised.

Von Kries, as stated on p. 232, fully recognises the altered aspect of the wave, its laboured and protracted growth, and its anacrotic event. But he fails to make us clearly understand the mechanism of the change, though the theory which he calls to aid is explained with his usual lucidity. He glances at the question of the arterial diameter possibly narrowed by stretching, and thus influencing the wave; but he turns with less uncertainty to the wave-rebounds, which he supposes to occur in an increased degree in the portions of the limb lying higher than the arterial distribution in question, thus causing in the latter the late arrival of important instalments of pressure.

By way of preliminary criticism let us at once point out a necessary distinction. The two recognised features of this pulse are so dissimilar and almost contradictory, that they could hardly be due to the same mechanism, or be found in any one case associated in equal proportions. The amplitude of the wave is *increased;* but, on the other hand, the tension is greatly *reduced,* and the tracing shows slowness of inflow and anacrotic rise.

Under ordinary circumstances these two conditions would exclude each other. Pulses giving the most ample waves are, as a rule, those in which the latter run the most rapid course; whilst slow anacrotic pulses usually perform but moderate oscillations. We specially refer to the tall and perpendicular wave of aortic regurgitation, and to the moderately elevated, but broad and anacrotic, wave of aortic stenosis.

In the pulse under consideration both results are observed : might not also both mechanisms be present, or at least represented by some equivalent combination ?

Regurgitation through the valves, which, in aortic valvular insufficiency, abruptly lessens the arterial pressure, is represented here by gravitation. Where is the element of stenosis, the presence of which is so plainly shown in the tracing ? The following experiments demonstrate that we are not dealing merely with the friction within arteries narrowed by stretching, nor with the resistance of collapsed arterioles, and of capillaries needing to be reopened by each systolic wave.

Experiment XLI.*

The patient is supposed to be standing : his arm hanging loosely in the ordinary neutral attitude, and his pulse, which will be found to be beating strongly, held under the continuous and somewhat firm pressure of the observer's fingers. He is now directed to turn the palm *forcibly* outwards, without lifting or moving the arm from the side. The immediate effect on the pulse is that it ceases to be felt, and is not felt so long as the previous firm pressure is kept up ; but with lighter pressure it is readily perceived, and with very light pressure it yields ample pulsations, contrasting in their duration and roundness with the sharper and shorter style of the previous pulse.

If, instead of rotation of the hand outwards, rotation inwards and backwards be performed, likewise with powerful strain, precisely the same results will occur.

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* These experiments will probably succeed best if the trained observer be his own subject.

In this experiment the changes observed in the pulse were almost identical with those induced by raising the arm ; yet the arm was kept dependent.

Experiment XLII.

An easier way of arriving at the same result (especially when the observer acts as his own subject) is to watch the pulse changes, seated in front of a table, the right forearm and hand resting at ease with their ulnar border on the table. The same straining movements may now be performed in the horizontal attitude of the arm. In proportion to the strain the pulse will be extinguished at the wrist as in the previous case.

Experiment XLIII.

The subject is made to lie at full length on his face on the floor, with arms gently curved so that the hands hardly extend beyond the level of the vertex. In this attitude the pulse will be normal and full, and firm pressure is to be kept on it. The subject is now directed to stretch the arm to its full length along the floor ; the pulse will immediately disappear for strong pressures of the finger, reappearing when the pressure is diminished.

In this case the same result is obtained as in raising the arm, and by the identical manœuvre ; but gravitation is excluded.

N.B.—In all these experiments, but especially in the present one, it will be observed that the effect will be proportionate to the *effort*. In this instance, if the subject should not only stretch the arm at full length, but should endeavour to reach beyond its length, the pulse may become absolutely extinguished so that even the lightest pressure fails to perceive its beat. This ultimate result is best obtained by combining with the muscular effort just mentioned either extreme rotation of the arm outwards, or especially extreme rotation inwards.

Experiment XLIV.

We may now repeat the original experiment, in the upright position of the trunk, using in succession the three degrees of extension previously hinted at:

(1) If the subject's arm be simply raised by the observer, the modification in the pulse will be of the kind usually described; and the pulsations, under suitable pressure, will be amplified.

(2) If the arm be pulled up forcibly, the pulse will be much reduced, and it would be hard to say that, even under the lightest touch, the pulsations were amplified.

(3) If instead of passive extension, the subject be made to raise the arm with the utmost voluntary effort, the radial pulse will almost cease to be felt; and this result will be the more marked if with elevation be combined a forcible rotation of the arm outwards or better still inwards.

CHAPTER XVII.

CONCLUSIONS FROM THE EXPERIMENTS WITH RAISED ARM.

Stenosis the Chief Agent.

THE co-operation of some form of local stenosis, in modifying the pulse in the way which authors have described, has now been fairly demonstrated. So obvious is this conclusion that we begin to doubt whether the original idea as to the nature of the phenomenon was not got from a false point of view, and whether the whole process is not from beginning to end connected with stenosis, the results varying with the degree of the latter. This doubt is strengthened by the fact that every detail of the pulse-change in question can be brought about independently of gravitation. That gravitation does, more rapidly and more effectually than any other means, reduce the contents and the size of the capillaries, will be at once admitted; but a moderate narrowing of the arterial supply clearly tends in the same direction, since total cessation of inflow would leave the limbs bloodless.

Suggested Interpretation of the Sphygmogram.

Sphygmograms, such as those given by Marey and by von Kries, which, we must assume, represent a moderate degree of the stenotic effect, might then be read as follows: Slight narrowing of the arterial channel (together with the draining effect of raising the arm) would lead to a diminution of the contents and calibre of capillaries, with probable increase of their frictional resistance and of the wave-rebound, and with great diminution or total loss of their elastic distension and recoil, and therefore of dicrotism in the pulse-trace.

The systolic wave would take a longer time in passing through;—the first rebound would occur early;—and the upstroke would become anacrotic. Owing to the slow fall of the systolic wave, a series of wave-rebounds would combine with it; and pressure, although not high, would be kept from falling early, and the downstroke would be very gradual and hardly notched by any dicrotism. This well-maintained pressure might be regarded as directly due to the relative smallness of the capillary calibre, whereby blood would be longer retained within the artery.

Nevertheless the wide oscillations, under a feeble extra-arterial pressure, clearly point to low wall-tension and to low intra-arterial pressure, and to a high degree of elastic mobility of the arterial wall. This, with the restricted blood supply, becomes in a measure a substitute for the elastic mobility of the capillaries seen in "dicrotic" pulses.

By lowering the wrist completely, all these features would be reversed, as shown in von Kries' sphygmogram.

Had the arm been raised forcibly, the pulse-tracing, far from yielding more ample oscillations, would probably have been very small. The blood supply being greatly diminished, muscular constrictive spasm would be set up in the artery, and the freedom of oscillation would cease. We are not aware of the existence of any sphygmograms taken in the extreme positions which have been described above.

As regards the tactile appreciation of the changes in the pulse, we suspect that the impression of increased amplitude may often have been intensified by its longer duration. This would be an instance of those tactile fallacies which Marey* has described under the name of "illusions du toucher." The sphygmogram shows a sufficient cause for this possible error. Concerning the reality of the dwindling of the pulse under extreme conditions no doubt can be entertained, although tactile appreciation is not in this case checked by the sphygmograph.

The Mechanism of the Arterial Stenosis.

The remaining question, as to the mode of production of stenosis, can be answered at least in part. We shall deal with it comprehensively, the case of the raised arm being regarded as only one variety in the group.

In the first place *muscular action* enters into the mechanism of all varieties, except that in which the arm is raised passively; secondly, the effect on the pulse is proportionate to the amount of muscular effort; and thirdly, the effect is most marked when the muscular effort is made in certain directions (rotation inwards or outwards).

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* *Loc. cit.*, p. 280.

The Site of the Stenosis.

Which is the artery affected? If the ulnar pulse should be found altered in the same way as the radial, the suspected interference must take place at or above the elbow. The ulnar pulse at the wrist is not, in most subjects, well adapted for the inquiry. We have at times, however, opportunities of feeling an abnormal ulnar artery, with superficial course. From cases of this kind we learn that the ulnar pulse suffers the same changes as the radial, and therefore that the brachial artery must be implicated. The latter is easy to feel from elbow to shoulder. If gradually explored in that direction by the finger, its pulse will be found to share, as high as the finger can feel, in the alterations induced in the radial and in the ulnar arteries.

On turning to the anatomy of the axilla we realise that the brachial artery passes here through a region full of powerful muscles, tendons and fasciæ. Behind it are the subscapularis, and the blended tendons of the teres major and latissimus dorsi; behind and to its outer side, the coraco-brachialis; in front and to its outer side, the coracoid head of the biceps; and crossing it anteriorly the insertion of the pectoralis major.

An important relation is the powerful and sharp edged tendinous web which connects the two last named tendons just below their insertion (at an acute angle with each other) into the tip of the coracoid process. The brachial artery passes behind this web, and, in the elevated position, would be received in the angle between the two muscles. It had occurred to the writer that this sharp edge might be the means of producing direct pressure on the artery either by position or by muscular effort. This remains, however, unproved; and it appears quite as likely that the muscles themselves are the agents of compression.

The Muscles Concerned in its Production.

Supposing all the muscles which have been enumerated were to be thrown into spasm at the same moment, the arm would be approximated to the side and the artery more or less compressed between muscular masses projecting, owing to their contractile increase in thickness, forwards and backwards, inwards and outwards, respectively.

One muscle, however, appears to be more intimately concerned than others with the movements which produce partial stoppage of the pulse. The effect can be obtained with flexed elbow, without moving the arm from the side. The requisite is then powerful supination or powerful pronation of the wrist. The effect can also be obtained with straight elbow and slightly abducted arm, but in that case the movement must be one of extreme rotation, outwards or inwards, of the arm at the shoulder-joint. In all these cases effect is taken either by or on the *biceps*. The influence of the contraction may be direct; but from the sensation communicated, during the performance of arm-strain, to the fingers applied to the brachial artery in its middle third, it would seem as though tension of the fascia itself were induced. Any possible influence of this kind, and any influence exerted on the brachial artery during muscular action by the aponeurosis of the arm, are matters deserving attention in the future. Again, the large and numerous branches distributed to the muscles of the arm, are capable of influencing the position and of controlling the displacements of the vessel.

At an earlier date the author had imagined that tension of the bicipital fascia at the elbow was the cause of the extinction of the pulse at the wrist; but further inquiry convinced him that the arterial compression occurred at a higher level.

The following facts tend to show that the axillary artery is the vessel involved, and that pressure is exerted by the muscles themselves and probably from before backwards rather than from side to side:

(1) Throughout the course of the brachial the venæ comites are placed on either side of the vessel;

(2) Just below the level of the subscapularis muscle the veins pass to the inner side of the artery and are joined by the basilic vein;

(3) Valves occur at this spot, suggesting the probable occurrence and the utilisation of pressure;

(4) The cephalic vein, after receiving the acromial thoracic blood, enters the axillary vein on its inner aspect, some distance *above* the upper margin of the pectoralis minor: in arching over this muscle, it imitates the suggestive curve taken nearer the latter by the acromial thoracic artery;

(5) The relations of parts are such that pressure exerted on the axillary artery from the front, from behind or from the outer side, but not from the inner or the inferior side, would not interfere with the venous flow.

Thus the group of muscles* surrounding the axillary artery on three of its sides would, during their simultaneous contraction, almost represent a sphincter for the axillary artery. If during the spasm the humerus were rotated, the head of the bone might become more prominent, and add to the effect of muscular pressure.

Is there any Purpose in the Arterial Stenosis?

The fact that the brachial pulse is greatly reduced or almost suppressed during violent action of the muscles of the arm is strongly suggestive of the probability of similar results elsewhere. Wardrop,† who appears to have been the first to describe them, long before the author's own independent observations, held and very ably argued that the blood supply to muscles in general was automatically checked or diminished by their contraction; and that the purpose of this arrangement, to which he gave the name of the *musculo-cardiac function*, was to stimulate the heart, by so much additional blood, to stronger contractions. Teleological questions are dangerous; more particularly in relation to the circulation and to muscular action, their scope is too extensive for the pages of this work. Still the subject is one worthy of renewed inquiry, all the more since Wardrop's ideas do not seem to have been taken up, and that physiological teaching has rather tended in a different direction.

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* Including the long head of the triceps.

† "On the Nature and Treatment of the Diseases of the Heart: containing also an account of the Musculo-Cardiac, the Pulmo-Cardiac, and the Veno-Pulmonary Functions." By James Wardrop, M.D., &c. London, 1851.

PART VI.

THE OBSERVATIONS AND THEORIES OF HENRI FOUQUET (1727–1806).

CHAPTER I.

FOUQUET'S METHOD AND CLASSIFICATION.

On the Uses of the Graphic Method.

As a preliminary to a description of Fouquet's diagrams of the pulse and to a brief account of his views, a further quotation from his book, in connection with the advantages of the graphic method, will be found of interest :

"Quoi qu'il en soit des premiers risques de ce travail qui a été suivi constamment pendant plusieures années, je n'aurai point à me plaindre du produit, s'il peut suppléer, jusqu'à un certain point, ce qui manque sur cette matière dans les auteurs."

"Les découvertes qu'on propose donc ici au public, consistent en des caractères ou des modifications variées du Pouls, relativement aux différens organes qui sont actuellement affectés ou menacés dans les maladies ; c'est-à-dire, en des notions particulières sur le système entier des Pouls *non-critiques*, qui, dans leur sens propre, doivent être appellés *Pouls des organes*, *Pouls organiques ;* dénomination d'autant plus exacte, qu'on verra dans la suite, que ces modifications peuvent encore s'étendre à certaines dispositions

des organes, dans l'état de santé ou de légère incommodité. Il y a plus, les expériences qui ont fourni la découverte de ces caractères, les ont en même temps représentés si distincts, si sensibles, et en quelque façon si palpables dans l'observation, qu'indépendamment des analyses ou explications raisonnées qu'on en donne, on a cru pouvoir encore parler aux yeux, et rendre ces différens caractères par des figures."

"Cette nouvelle méthode présente, comme on peut en juger, les plus grandes facilités. 1. Avec le tact le moins exercé, tout Médecin, toute personne même qui n'est pas de l'Art, peut apprendre d'elle-même a connoitre l'espèce de Pouls, affectée individuellement à chaque organe ; du moins, puis-je bien certifier qu'une simple exposition orale, ou quelques traits jettés à la hâte sur du papier, sur une carte, auprès du lit des malades, ont suffi à beaucoup de jeunes gens pour qu'ils soient parvenus dans très-peu de temps, à acquérir sur ces caractères particuliers du Pouls, les notions majeures et fondamentales."

2. "Il n'est surement pas de moyen plus commode, pour saisir et retenir les complications qui se rencontrent dans un seul et même Pouls, lorsque la maladie intéresse plusieurs organes à la fois ; ce qui n'est pas aisé, à beaucoup près, par les signes indiqués dans les ouvrages des modernes, toute excellente qu'est leur méthode, toute supérieure sans doute qu'on la trouve, une fois qu'on la possède. On peut remarquer en effet, qus ces signes consistent uniquement en des combinaisons très-rapides de plusieurs manières d'être de l'artère, soit dans ses mouvemens, soit dans ses dimensions; combinaisons toujours embarrassantes qu'il faut savoir décomposer pour en tirer un prognostic; ce qui demande, quoi qu'on en dise, beaucoup de sagacité, beaucoup de finesse dans le tact, et un long exercice de la part de l'observateur."

3. "Cette méthode est de la plus grande ressource pour les jeunes gens, qui, outre les difficultés déjà exposées de la méthode des modernes, sont sujets a se dégouter de l'observation en tombant sur des maladies dont la marche est forcée, c'est-à-dire, dénaturée par des manœuvres violentes et continues: au lieu qu'avec la nouvelle méthode, ils peuvent attraper, chemin faisant, les caractères de quelques Pouls *non-critiques*, et par-là, se trouver en état de discerner les plus légers mouvemens de la nature ; ce qui les arrête utilement et les rappelle auprès des malades, en excitant leur curiosité."

The Theories on the Pulse Adopted by Fouquet.

The Critical Pulses of Solano.

Fouquet was not tempted to originate any novel theory, being strongly swayed by authority, but placed his great powers of observation entirely at the service of the theories of the day and especially of that of his teacher and patron, T. de Bordeu; at the same time striving to show that these theories were not truly novel but revived from Galen and his successors after a period of oblivion.

Solano's *critical pulses* and de Bordeu's *organic pulses* supplied the basis and the material for his work, the first relating to prognosis, and the second, the study of which he made more specially his own, to diagnosis.

From an obscure town in Andalusia, Solano de Luque* (1685-1738) revolutionised the clinical teaching on the pulse. His disciple Nihell † brought the new doctrine to this country, whence it was gradually diffused. Briefly stated, Solano's theory assumed that the several crises, by hæmorrhage, by vomiting and diarrhœa, by diaphoresis, and by diuresis, were announced by definite changes in the pulse. An account of the varieties described by him and of other interesting particulars will be found in Ozanam's work (*loc. cit.* pp. 112–118).

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* "Lapis Lydius Apollinis," in fol. Madrid, 1731.

† "New and Extraordinary Observations, Concerning the Predictions of the Various Crises, by the Means of the Pulse," 8vo, London, 1741.

The Organic Pulses of de Bordeu.

In the absence of crises, the many abnormalities of the pulse remained to be accounted for. These *non-critical pulses* Théophile de Bordeu* (1722–1756) classified into groups under the name of the *Organic Pulses.*

Reviving the errors of the Greek physician Actuarius (eleventh century), although little conscious of the prophetic truth of the principle upon which they had been based,

> "The more sensitive parts of the body modify the pulse in consequence of the pain which they feel; and the less sensitive modify it in relation to the special affection from which they suffer"—("De Method. Med.," lib. i. c. ix [Venetiis], quoted by Ozanam, *loc. cit.* p. 26).

he conceived that the varieties in the pulse were determined by the various organs. Actuarius had professed to identify the seat of disease in the liver, the spleen, the kidneys, the bladder, the stomach and the intestines. De Bordeu carried this analysis further, but began by dividing the pulses into *superior* or *supra-phrenic*, and *inferior* or *sub-phrenic.* The superior was supposed to be rebounding or dicrotic, its chief varieties being the pectoral, the guttural, and the nasal. The inferior, distinguished by inequality and skipping action, was specialised into organic varieties as the stomachal, the intestinal, the hepatic, the splenic, the renal, the uterine, and the hæmorrhoidal pulse.

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* Th. de Bordeu, "Recherches sur le Pouls, par rapport aux crises." Paris, 1756.

FIG. 174A.—FACSIMILE OF FOUQUET'S* ENGRAVING.

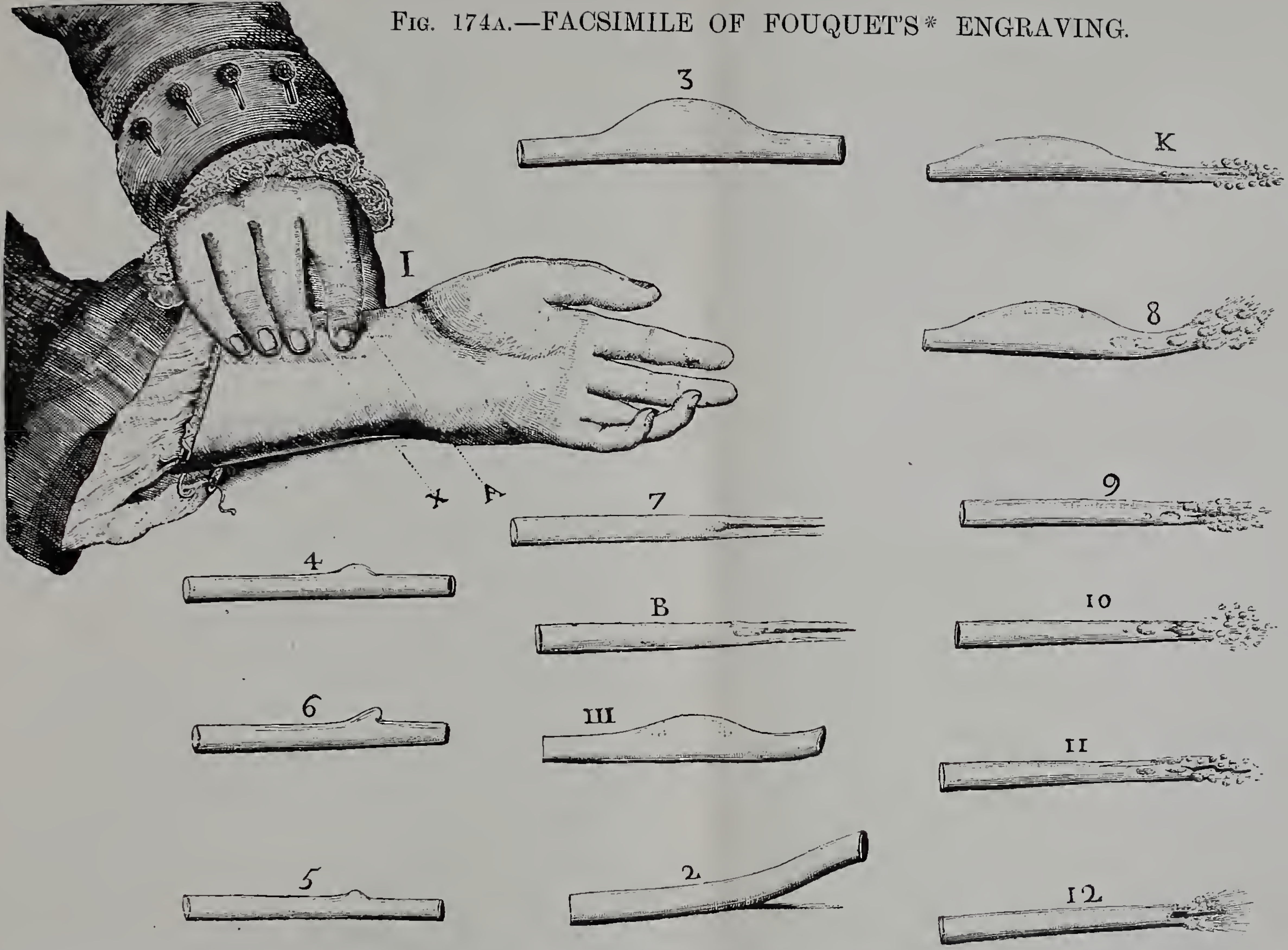

FIG. 1.—Représente une main qui tâte le pouls avec les quatre doigts en place, et dont néanmoins l'index et le medius se trouvent, contre les règles, former entre eux un intervalle considérable, afin de laisser entrevoir un caractère organique qui est le stomachal. X. Le Caractère du Pouls Stomachal qui s'élève entre l'index et le Medius. A. L'Apophyse Styloide du Radius. FIG. 2.—*Le Caractère du* Capital. FIG. III.—*Le Caractère du* Guttural. FIG. 3.—*Le Caractère du* Pectoral. FIG. 4.—*Le Caractère du* Stomachal. FIG. 5.—*Le Caractère de l'* Hépatique. FIG. 6.—*Le Caractère du* Splénique. FIG. 7.—*Le Caractère de l'* Intestinal. FIG. B.—*Autre Caractère* Intestinal. FIG. 8.—*Le Caractère du* Nazal. FIG. 9.—*Le Caractère de l'* Utérin. FIG. 10.—*Autre Caractère* Utérin. FIG. 11.—*Autre Sorte d'* Utérin. FIG. K.—*Le Caractère de l'* Hémorrhoïdal. FIG. 12.—*Le Caractère du Pouls dans la* Dyssenterie *ou du* Dyssentérique.

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* ESSAI SUR LE POULS Par rapport aux affections des principaux organes, avec des figures qui représentent les caractères du Pouls dans ces affections. Ouvrage augmenté d'un Abrégé de la Doctrine et de la Pratique de Solano, d'après les livres originaux et autres ouvrages, Espagnols, et d'une Dissertation sur la Théorie du Pouls, traduite du latin de Mr. Fleming, Membre du Collége des Médecins de Londres. Par Mr. Henri Fouquét, Docteur en Médecine de l'Université de Montpellier, Médecin de la méme Ville, et de la Société Royale des Sciences. A Montpellier, chez la Veuve de Jean Martel, Imprimeur du Roi et des États. M.DCC.LXVII. Avec Approbation et Privilége du Roi.

The Individual Features of the Organic Pulses Studied by Fouquet.

Beyond attributing to these varieties the general characters of "a pulse of irritation" de Bordeu had failed to assign clearly to each of them individual and distinctive tactile characters. Fouquet set himself the task of supplying this deficiency, and he refers to his results in the following terms:

"Or, c'est précisément dans ces modifications, soit isolées, soit compliquées de l'artère ou de sa surface, que consistent les nouveaux caractères des Pouls *non-critiques* ou *organiques*,* et il n'est besoin que de les combiner avec le *rebondissement*, le développement du Pouls, et quelques autres circonstances détaillées dans le livre des *Recherches*, pour avoir en même-temps la connoissance la plus positive et la plus complette du Pouls *critique* des modernes, et des organes par ou les crises doivent se faire (*loc. cit.* p. xv).

Fouquet's Tactile Method.

The more important rules laid down by Fouquet (*loc. cit.* chap. i.) are the following:

"The index should always be nearest the hand, and should take its bearing on the base of the styloid process, the wrist being grasped from its radial side."

"Two or three fingers are essential; but, *more veterum*, Fouquet recommends four for the sake of a better hold and of a more ample contact. They should be gently pressed against each other, and applied to the artery either vertically, or on the flat

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* Within the class of the organic pulses, Fouquet (*loc. cit.* p. 21) distinguishes those which are associated with morbid states of organs, and which he terms the "symptomatic" or "non-critical" pulses, and the larger group of "organic" pulses pure and simple, which are connected with a merely exaggerated function of the organs.

The "critical" pulses present three phases corresponding to the first and second coction, and to excretion or expulsion (*loc. cit.* p. 47).

(when the thumb more fully encircles the wrist), and their individual pressure should, with occasional exceptions, be the same."

"Gradations and alternations of pressure are to be so arranged that the freedom of pulsation or the arterial diameter are not interfered with, even when the deep situation of the artery necessitates considerable pressure."

Fouquet's Classification of the Organic Pulses, and Description of their Tactile Features.

The individual features of each variety are best studied in the uncomplicated phase; that is, in the organic pulses pure and simple.

Fouquet's classification, differing little from that of de Bordeu, distinguishes a superior and an inferior type of pulse—the thoracic type being usually large, tall, and strong in comparison with the small, contracted, and less easily felt abdominal type—and the following organic varieties: the capital, the guttural, the pectoral, the epigastric or gastric, the hepatic, the splenic, the abdominal or intestinal, the renal, the diaphoretic, the hæmorrhagic (including the nasal, the uterine, and the hæmorrhoidal), and lastly the dysenteric.

Of all these varieties not one has kept its place in our clinical terminology. There is indeed but one organ, the heart—and this is not represented in Fouquet's nomenclature—of which the affections are at the present time studied in the pulse.

It is a matter for our consideration whether this neglect of the pulse-indications relating to other organs may not have been pushed too far. Of the diagnostic value of the pulse in cardiac affections no doubt can exist.

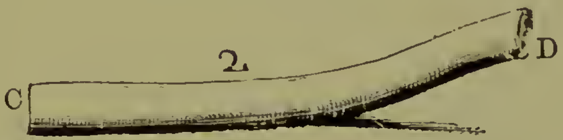
CHAPTER II.

FOUQUET'S PULSE-TYPES—WITH CRITICISMS.

The "Capital"-Pulse.

THIS pulse, observed in cases of head affections, is distinguished by a rise of the distal portion of the vessel, as shown in Fouquet's illustration.

FIG. 175.



The radial pulse, under four fingers : C, heart side ; D, wrist side.

" L'artère semble fixée sur le niveau de son plan sous les doigts annulaire et auriculaire; tandis que la partie antérieure s'élève considérablement au dessus de ce niveau souvent avec une liberté, une plénitude, et une force très marquées. Quelquefois, cette élévation se prend de plus loin, par exemple dès le doigt annulaire, d'où par gradation il augmente jusqu'à l'index, et par de là en frappant dans cette proportion la rangée des doigts ; de sorte que l'artère dans son élévation forme un angle aigu avec la ligne horizontale de son plan naturel."

" L'artère y est ordinairement fort roide et fort tendue ; vers l'extrêmité digitale surtout, l'impression en est sèche et vive, comme le serait celle d'une corde mince ou d'une ficéle. Environ sous le *médius et l'index*, l'artère fait sentir quelque chose de *passif* et de pénible, comme si elle était soulevée méchaniquement, c'est-à-dire sans paroître s'aider de son activité ou de sa faculté propre."

> "Ce Pouls fait encore appercevoir quelquefois un *renflement* leger ou *élargissement* plus ou moins sensible, une espèce de *large* peu décidé de la partie *brachiale* ou postérieure de l'artère, tandis qu'à la partie antérieure, elle reparoît sous sa forme cylindrique, en se soulevant assez fortement on assez brusquement pour en repousser le *médius et l'index* . . . Ce Pouls . . . est tantôt élevé . . . tantôt profond et concentré au point de ne laisser sentir que le bout digital de l'artere, dont la sensation sur les doigts est comparable à celle d'une portion de ver lumbrical qui souleverait par intervalles le *médius et l'index*, mais qui forceroit principalement sous le dernier, ayant tout le reste du corps caché ou immobile."

Comment.

The sensations so graphically described have been fully analysed in these pages; and this description alone would prove that Fouquet was familiar with the feel of the proximal, of the distal, and of the intermediate ictus, although he had not clearly defined them nor isolated one from the other. The laboured progress of the wave under the central fingers is precisely what is felt when four fingers are used; the worm-like and "underground" motion are well contrasted with the free, upheaving distal ictus, which he correctly localises mainly under the index. Again Fouquet had felt the expansion of the artery behind the pressure of the fingers, as well as its partly flattened condition, whilst the "cylindrical feel" he obtained at the distal segment of the pulsation informs us that the pressure he employed was of the moderate kind described as pressure ii.

It is obvious, however, that this pulse-type is composite, inasmuch as its several features must have been obtained with different degrees of pressure; and also essentially composite, as pulses are when felt with several fingers concurrently (see p. 144).

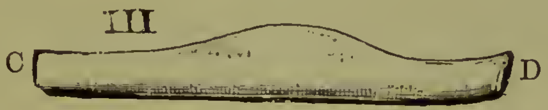
As to the clinical value of the type very little need be said. Head affections and injuries, and cerebral excitation by congestion, by drugs, or by stimulants, often provide us with pulses exactly such as Fouquet describes, and in this case his imagination did not far outstep observation.

The Guttural or Throat-Pulse.

The annexed figure shows some of the points described by Fouquet:

"Ce Pouls est caractérisé par une éminence ou renflement considérable en forme d'onde, de la partie un peu postérieure de l'artère ou de l'espace pulsant, et par la dureté le mouvement libre et en quelque façon détaché de l'autre partie qui retient sa forme cylindrique assez dépouillée en s'élévant avec force, le tout à peu près comme dans le Pouls capital."

FIG. 176.



The throat-pulse differs from the head-pulse in presenting less of a peripheral rise, and a more decided and centred proximal swelling, often encroaching on the distal region of the pulse:

"Sous ce renflement même on sent l'artère conservant sa forme ronde ou cylindrique, comme si elle était enguaînée dans une autre artère vuide, dont les parois seroient très-minces, très-déliées et renflées par le milieu, c'est aussi ce qui fait paroître ce Pouls un peu *redoublé* et un peu *ondoyant* . . . ."

". . . . Dans la partie la plus dure et la plus étroite de l'artère, c'est-à-dire dans son extrêmité digitale on sent quelquefois comme une espèce de *nœud mobile* ou *bourlet* très-léger, qui paroît environner l'artère en suivant le mouvement progressif de la colonne du sang, à chaque *diastole*,* et qui commence à environ l'endroit de l'artère ou porte le *médius*, en s'effaçant de plus en plus dans sa progression."

Fouquet remarks that the features of this pulse might have been almost compounded of those of the capital and of the pectoral varieties.

Comments.

The features so accurately described are those which may be obtained in any pulse fairly strong and full, by using, for palpation, three or four fingers. The fact that the middle finger is the centre of sensation shows that pressure iii must have been employed. The double feeling, as of a bulging sheath around a cylindrical artery, must have been obtained either through a rapid variation in the pressure of the fingers, or more probably as part of a blended sensation, the intermediate fingers perceiving the ictus, and the distal finger the cylindrical shape of a rather tense vessel. In the distinct appreciation of these overlapping sensations we have another proof of Fouquet's keen powers of observation, which are also shown in his remarks on the "travelling knot" felt in the artery.

The Pectoral or Chest-Pulse.

This variety is easily recognised by its ample rise, its fulness, and its suppleness.

"Il est principalement marqué par un soulèvement ou élévation du milieu de l'artère ou espace pulsant, qui paroît sous les doigts comme une petite montagne unie, bien figurée et un peu molette, l'une et l'autre extrêmité de l'artère se mouvant au niveau de leur plan et sous la forme ordinaire ou naturelle ; en sorte que le profil supérieur de l'artère décrive une espèce d'arc."

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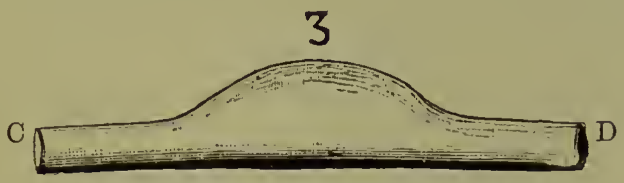
* "Diastole" is used by Fouquet in the arterial sense.

FIG. 177.



"This was probably the pulse described by the ancients as *pulsus eminuli, prominuli.* The "little mountain in the pulse" is more sharply contoured, although with increased hardness such as belongs to "irritation," in pleurisy, hæmoptysis, penetrating chest wounds, etc. ; but in pneumonia it is much softer as well as wider, so that the pulsating surface feels like a small gut inflated with air at each beat. The pectoral pulse is also observed on the off-days of malarial fevers, probably under the influence of cinchona, known to give rise to a tall and strong pulse which is at the same time soft."

Comments.

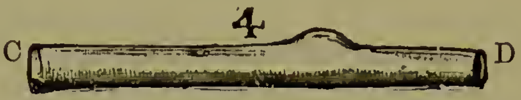
Every physician will subscribe to the accuracy of this description in connection with many acute or subacute affections of the chest. Renewed clinical investigations into the tactile characters of morbid pulses may perhaps in the future lead to this pulse-type being once more recognised.

The Epigastric or Stomach-Pulse.

Fouquet describes the stomach-pulse as the main type of the epigastric group of pulses, comprising the hepatic, the splenic, and the colic pulses.

"Le Pouls de l'estomac ou *stomachal* est invariablement caractérisé par une petite éminence qui s'élève entre l'index et le médius ; cette éminence paroît même quelquefois entrer ou monter assez avant dans l'intervalle des extrêmités de ces deux doigts, à peu près comme une petite piramide dont la pointe serait mousse ou un peu arrondie."

FIG. 178.



Belonging to the inferior (subphrenic) variety, this pulse is much less tall; it is cylindrical throughout except where it rises into a small pyramid. Moreover it is usually stiff, and contracted as though by spasm, and displaying "irritation," although the beats are of moderate size and not unequal. Nausea, vomiting, and cardialgia occasion more and more contraction with stiffness, to which are added inequality and "concentration." The immediate approach of vomiting, as may be easily observed after the use of emetics, and after the first effects of the dose, causes a remarkable change :

"La petite éminence piramidale paroît comme s'arrondir avec un espèce de tremblotement de l'artère mêlé de convulsion . . . . J'ai observé dans plusieurs occasions une espèce d' *ascensus* et de *descensus* du Pouls *stomachal* très marqués. Dans le premier cas l'éminence piramidale frappe beaucoup plus vers le côté du *médius*, et presque point sur le côté de *l'index ;* elle paroît même vouloir s'étendre, s'élargir et s'arrondir de plus en plus comme pour se fondre ou se transformer en *pectoral*, en gagnant toujours vers le médius . . . . on pourrait le qualifier de *Pouls du cardia ou Pouls stomachal supérieur*."

"Dans le second cas, la petite éminence piramidale fait le contraire ; elle paroît se retrécir et s'affaisser en se rangeant de plus en plus du côté de *l'index*, et ne se faisant presque pas sentir du côté du *medius* . . . . on pourrait l'appeller de son contraste avec l'autre, *Pouls stomachal inférieur*.

> "Le caractère stomachal est fortement marqué sur le Pouls après le repas, malgré le trouble et l'espèce de convulsion fébrile qu'y répand le travail de la digestion. J'ajouterai que la sensation de la faim modifie encore le Pouls au caractère *stomachal :* il dépend d'un chacun de reconnoître le fait."

A description of the influence produced on the pulse by drinking is interesting in connection with the attention given by modern physiologists, and in particular by Dr. Lauder Brunton, to the agency of sipping in its relation to cardiac action :

> "Chez ces sujets les mieux constitués et les mieux portans, j'ai observé plusieurs fois que la boisson d'un verre d'eau ou de ptisane ordinaire troubloit soudainement le calme ou la sérénite du Pouls, et lui imprimoit le caractère particulier quoique momentané du *stomachal* ou même de *l'intestinal*, lorsque cette boisson venoit à occasioner quelque détente dans le bas-ventre ou quelque mouvement d'entrailles ; ce phénomène m'a paru beaucoup plus sensible ou plus aisé à observer sur les Pouls des convalescens" (*loc. cit.* pp. 36–37).

Comments.

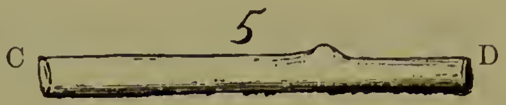
We have found Fouquet's observations so correct hitherto that we expect him to be right in a matter of direct experiment repeated, as that of emesis, almost every day in his practice. We cannot follow him in the distinction which he draws between the superior and the inferior stomach-pulse. These differences we note as probably real, but we do not trust the localisation.

The descriptions are remarkable for their graphic precision. We notice the expression "*frappe beaucoup plus vers le côté du médius,*" etc., which supplies an adequate and complete picture of the distal ictus.

The Hepatic or Liver Pulse.

It is much to his credit that Fouquet devotes but a few lines to the description of this variety, in addition to the illustration supplied.

FIG. 179.



" Ce caractère est remarquable par une éminence à peu près la même dans le fond que celle du Pouls de l'estomac et qui s'élève au même endroit, en frappant également entre le doigt indice et celui du milieu. Cette éminence differe pourtant de celle du stomachal par quelques circonstances ; elle n'est ni si marquée, ni si forte, ni si élevée ; elle est plus légere, plus rétrécie, plus séche, ainsi que le porte la Fig. 5^{e}.

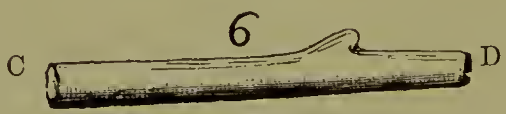
" D'ailleurs, l'artère est dans ce Pouls incomparablement plus tendue, plus rétrécie et plus concentrée que dans le stomachal ; les pulsations moins vives et plus irrégulières."

The Splenic or Spleen-Pulse.

This variety also belongs to the epigastric class of pulses :

" C'est toujours une petite éminence qui frappe ou s'élève entre le *médius* et *l'index* comme dans le stomachal, mais qui paroît monter ou s'allonger un peu plus dans l'intervalle de ces deux doigts, comme si elle étoit ou plus haute ou moins arrondie ; ce qui la distingue sur-tout, c'est qu'elle paroît coupée verticalement du côté qui répond a l'index, et que vers la base ou le pied de cette coupe verticale, on sent comme une échancrure, tandis que du

FIG. 180.



côté opposé elle conserve sa déclinaison jusques sous le medius, comme une moitié d'un petit pectoral."

"On trouve souvent dans ce Pouls l'extrêmité digitale de l'artère fort rétrécie comme dans *l'intestinal ;* mais la partie postérieure ou brachiale reste large ou conserve son diamêtre naturel."

Comments.

If we overlook the localisation and the name, the description, for its own sake, excites our astonishment. Such an expression as the "half of a small pectoral pulse" proclaims that Fouquet's mental conception of the shape of his tactile pulse-wave was as clear as that we now have of the sphygmographic pulse-wave. It seems the more incredible that impressions capable of so definite an expression should have been, as far as we know, exclusively obtained and described by one man, 125 years ago, and never noticed again to the present day, in spite of his lucid description.

The vertical line, which he depicts in words more fully than in the engraving, and the indentation at its base suggest to us the first dawning upon him of a perception, soon to be more completely realised. He perceives that the ictus does not travel onwards ; and he is beginning to perceive that its march is retrograde.

CHAPTER III.

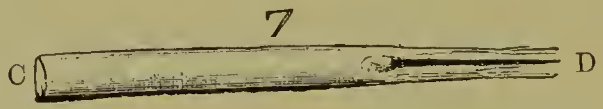
THE ABDOMINAL AND THE HÆMORRHAGIC PULSES OF FOUQUET—WITH CRITICISMS.

The Abdominal Pulse and, in Particular, its Intestinal Variety.

Fouquet includes in a capacious group the pulses corresponding to all the organs, (even the kidneys), contained within the abdomen. The general *abdominal* feature of the pulse is " concentration, hardness, and contraction of the artery especially in its digital portion, and briskness of its pulsations with inequality." The *intestinal* feature is more fully described :

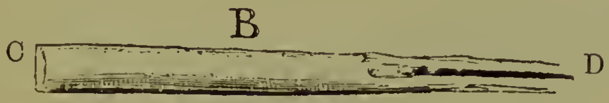
> " On distingue d'abord un rétrécissement singulier du bout digital de l'artère. Là se trouve, dans presque toutes les pulsations, comme un osselet ou petit grain de sezame mal formé, qui depuis environ le point de l'artère qui répond à l'intervalle entre les bouts du *médius* et de *l'index* (quoiqu'en se rapprochant davantage de ce dernier) qui, dis-je, depuis cet endroit où il se fait sentir sous une forme à peu près globuleuse, se porteroit ou glisseroit avec

Fig. 181.



rapidité à travers l'artère sous tout l'index, jusque par de-là l'apophyse du rayon, en paroissant s'allonger ou s'aminçir de plus en plus dans ce trajet, en forme de petit dart ou d'aiguille ; semblable en quelque sorte à un globule ductile tel que quelques observateurs se plaisent à représenter les globules sanguins, qui se modifieroit de la manière exposée pour passer à travers cette extrêmité rétrécie de l'artère, comme à travers un vaisseau capillaire ou lymphatique. On pourrait encore se peindre l'impression de ce globule dans sa forme et ses mouvemens, par l'exemple d'une épingle dont la tête frapperoit le bout du doigt indice, à commencer environ au côté qui avoisine le médius, ou même à l'intervalle entre ces deux doigts, et le reste ou la hanse s'étendroit ultérieurement vers la main du malade, en paroissant fuir sous le doigt comme un petit trait ou une aiguille fine."

FIG. 182.



"Dans ce Pouls l'artère est fort rétrécie et fort roide, sur-tout à l'extrêmité digitale qui renferme le petit dard ; . . . . bien souvent la partie postérieure ou brachiale se sent à peine ; . . .—d'autrefois il faut presser fortement les doigts, pour reconnoître l'extrêmité digitale qui ne donne que comme un petit filet dur dans ses pulsations."

The Pulse of Ascites.

The pulse of *Ascites* is harder and more tense and contracted than the intestinal pulse. The distal end of the artery is more contracted than the proximal, and the pulse is unequal, with usually a slight fremitus at its termination.

Owing to the pressure on the diaphragm, and to the cough and expectoration due to the resulting serous accumulations, a *pectoral* quality is often combined with this pulse.

The Renal Pulse.

Concerning the *renal pulse* Fouquet says :

> " Nous n'avons pû découvrir sur le Pouls des urines des signes assez méchaniques ou assez distincts, pour les réprésenter par des figures ou les dessiner comme les autres pouls. Tout ce que nous avons a remarquer sur ce Pouls, c'est qu'il est souvent *dur*, serré ; . . . . Dans quelques flux d'urine occasionnés par l'usage des remèdes diurétiques et apéritifs, ce Pouls avoit beaucoup de dureté et une espèce de gêne dans ses pulsations. Il paroissoit à ce Pouls qu'on faisoit, pour ainsi dire, violence à la nature ou qu'elle se faisoit violence à elle même."

Comments.

Judged in the light of our present knowledge Fouquet's descriptions are remarkably correct. To the present day we speak of the filiform or wiry pulse of peritonitis ; only, Fouquet was also able to recognise the ictus, which our description neglects. His remarks on the mechanical effects of ascites, and on the resulting modification of the pulse are true to nature. His reticence as to the renal pulse is distinctive of his accuracy of observation. The one character which he discovers in it is that which now often guides our diagnosis in the absence of other helps : " it is hard and it is laboured."

The written description of the intestinal pulse does not in its entirety agree with the drawing ; it does, however, agree with the latter in its concluding part. It is noteworthy that the simile of the pin, and the drawing itself, both suggest that the round body or head is felt under the index, but that it is not felt elsewhere, and that it is the point and the shank of the pin which appear to escape towards the hand.

The Pulse of Diaphoresis.

The name *Pulsus Undosus* belonged to this pulse in antiquity; Solano calls it *inciduus*. Fouquet proposes to term it in a more general way, *the Pulse of the cutaneous organ, or of the periphery of the body*, an expression which reminds us of the recent remarks of von Frey (see p. 252) on the dicrotic pulse. Here again, as in the renal pulse, Fouquet finds nothing to delineate, and little to describe.

> "L'artère est renflée au milieu de l'espace pulsant dans la forme à peu près du caractère pectoral, mais beaucoup plus que dans ce dernier Pouls; elle est d'un large, quelquefois même d'un lâche qui la fait paroître comme anévrismatisée; de sorte que dans ses premiers soulèvements ou premières pulsations, elle fait sous les doigts la sensation d'une courbe molle et un peu ondoyante."

This pulse is observed in some continued fevers, in small-pox before or during the eruption, in various acute maladies, and in phthisis, associated with abundant expectoration and night sweats.

The Pulses of Hæmorrhage.

1. The Nasal Pulse.

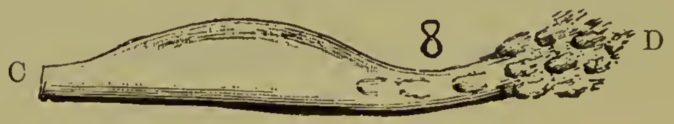
Fouquet distinguishes four pulses of hæmorrhage, the nasal, the uterine, the hæmorrhoidal, and the dysenteric. In some cases of hæmatemesis he had found a trace of the same pulse-character; but from their limited number he could not venture to evolve a special type.

> "Le Pouls général des hémorrhagies est principalement remarquable dans notre méthode par l'impression d'une sorte de petits corps ronds ou petits grains très-fluxiles et très-rapides

dans leur transition, qui se font sentir à l'extrêmité digitale de l'artère, comme à la file l'un de l'autre; parvenus à environ la base de l'apophyse du radius, ces petits corps ronds semblent se briser en heurtant contre cette apophyse, ou se diviser et se répandre çà et là en éclats plus ou moins nombreux, plus ou moins marqués ; d'où résulte dans cet endroit c'est-à-dire, au bout de l'extrêmité digitale de l'artère, une espèce de fourmillement plus ou moins sensible, à chaque diastole. . . .

Le Pouls nasal simple, se fait reconnoître pour l'ordinaire par un renflement ou élargissement de la partie brachiale de l'artère, et par une espèce d'applatissement à son extrêmité digitale, qui, sous tout *l'index* la fait paroître à peu près comme un petit encan nerveux ou un nerf plus ou moins applati. A l'endroit même de cet applatissement, on sent les petits corps ronds, dont nous avons parté plus haut, qui paroissent comme allongés, en filant à la queüe l'un de l'autre, et très-fluxiles ou peu marqués dans leur forme, tels qu'on peut se représenter des gouttelettes d'eau pressées entre deux lames quarrées de verre, qui iroient et viendroient séparément entre ces deux lames, par les pressions alternatives aux angles opposés.

FIG. 183.



"*Ce Pouls a encore cela de particulier* que les petits corps ronds semblent heurter contre un obstacle vers l'apophyse du rayon qui les brise et en refléchit les éclats en arrière sur la série même de ces petits corps; aussi sur quelques Pouls, l'artère en, paroît-elle dans son extrêmité digitale comme légèrement festonnée si on peut employer ce terme, à sa surface, et comme déchirée en petits lambeaux tout-à-fait au bout, quoique le plus ordinairement cela se réduise à un fourmillement grênu très-marqué, un peu au-delà du doigt indice ou au côté de ce doigt vers la main, lequel fourmillement semble distendre et amincir en cet endroit les parois de l'artère."

"Quelquefois on diroit qui il n'y a dans la portion applatie ou digitale de l'artère qu'un ou deux de ces petits corps ronds assez bien formés qui passent prestement sous les doigts, à peu-près

comme s'ils tenoient au bout d'un ressort très-délié, très-mince, ou languette très-élastique qui les lance, en se détendant, contre le prétendu obstacle de l'apophise du radius."

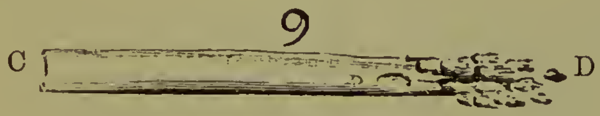
"Les accidens particuliers au caractère du Pouls nazal, sont l'élévation des Pouls *supérieurs ;* la dureté et une espèce de vuide dans l'extrêmité applatie de l'artère, un soulèvement tout a fait au bout qui approche de celui du *capital*, avec de la roideur et une certaine fougue dans quelques pulsations . . . . Quelquefois encore ce Pouls se trouve fort concentré, embarrassé, avec un *rebondissement* obscur. . . . . Le *dicrotus* appartient spécialement au Pouls *critique*."

The nasal pulse is also observed in coryza, etc. Hæmorrhage need not occur unless the vessels be predisposed to excretion. Fouquet, indeed, recommends much caution in venturing to predict epistaxis.

2. The Uterine Pulse.

"Ce Pouls est en général beaucoup moins élevé et moins fort que le nazal, quelquesfois même on le trouve si concentré qu'il est besoin d'une pression particulière des doigts, principalement de *l'index*, pour sentir les petits corps on le fourmillement grenu de l'extrêmité de l'artère. Souvent ce Pouls est lent, l'extrêmité digitale de l'artère n'y est pas sensiblement applatie comme dans le *nazal*, elle paroit au contraire conserver sa forme cylindrique ; mais aussi est-elle rétrécie, un peu profonde, et ses pulsations un peu inégales comme dans un léger *intestinal*. De plus, les petits corps ronds ne sont pour l'ordinaire dans ce Pouls, ni si secs ni si formés que dans le nazal."

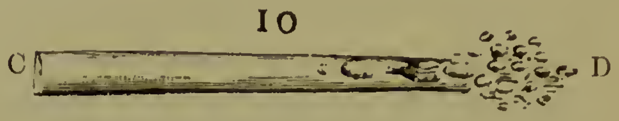
FIG. 184.



Then follow remarkable descriptions of the varieties of the uterine pulse; of these only short passages can be quoted:

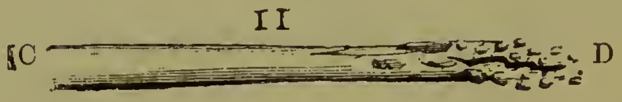
"Quelquefois le premier de ces petits corps ronds ou le plus sensible fait sur les doigts, en partant, une impression à peu près égale a celle du petit bouton de la sourdine d'une montre qui bat actuellement et dont on sent en même temps la petite détente.”

Fig. 185.



“ Sur d'autres on remarque comme une espèce d'intersection entre le premier des petits corps ronds et l'extrêmité de la languette élastique qui les lance à peu près a l'intervalle entre *l'index* et le doigt du milieu en se rapprochant d'avantage de *l'index* . . . . J'ai encore senti dans certains de ces Pouls comme une espèce de *cassure* en zic zac, très-légere, très-fugitive, à l'extrêmité digitale de l'artère, laquelle revenoit à chaque diastole.

Fig. 186.



“ D'autres fois, il semble que la colomne du sang parvenue à l'extrêmité digitale de l'artère, recule en arrière en lançant en avant le petit corps qui se brise vers l'apophyse du rayon, etc. . . . .”

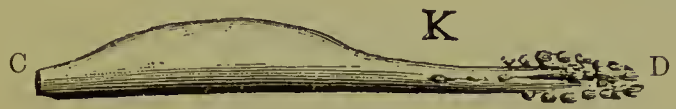
The pulses of pregnancy, of the lochia, and of leucorrhœa are sub-varieties of the uterine.

3. The Hæmorrhoidal Pulse.

Here again we find the specific character of the pulses of hæmorrhage, a fine formication at the digital extremity of the pulse. The distinguishing features are the following :—

“ Les petits corps ronds paroissent beaucoup plus petits et en même temps très-secs, le fourmillement semble plus resserré ou s'exercer dans un plus petit espace, et les fragmens des petits corps ronds sont très-peu marqués ; en sorte que c'est plutôt un leger frémissement qu'un fourmillement grenu qui se fait sentir sous *l'index* et par delà."

FIG. 187.



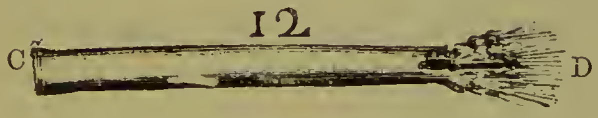
Moreover the artery presents a swell not unlike, though smaller than, that special to the pectoral pulse; and at the same time some hardness and contraction of the distal portion; the proportion as to thickness or volume between the distal and the proximal portions being often as 2 to 8. The rhythm is sometimes irregular (*impar citatus*).

4. The Dysenteric Pulse.

This pulse agrees very closely with the preceding, but has less height and fulness, and is more frequent and unequal, or even intermittent.

"On y sent par intervalles l'aiguille ou dard de l'intestinal vrai; les petits corps ronds et leur fragmens sont peu sensibles, et souvent ces fragmens paroissent assez nombreux et assez fins, pour figurer le bout de l'artère à côtè de *l'index* ou au-delà, en une espèce de petite brosse de peintre, ou manière de petite aigréte, comme s'ils s'éparpilloient en divergeant."

FIG. 188.



A similar pulse has been observed by Fouquet in connection with the colicky pains often preceding or accompanying the onset of a menstruation.

It should be noted that in violent dysentery the pulse is apt to be much taller, with a sort of rebound, more frequent and tense, and the small round bodies more marked.

Comments on the Last Four Descriptions.

The pulse-sensations described by Fouquet under the heading of the Hæmorrhagic Pulses, and the drawings in which these sensations are expressed, have probably excited more incredulity and ridicule than the apparently less imaginary varieties previously detailed. Fouquet's powers of observation are now so well known to us that we should feel it rash to doubt their correct working in this case. It will be found that the sensation described is a reality, though one of the similes used, that of spherules, is somewhat misleading. The other simile will be recognised by the dullest touch. The elaborate descriptions of Fouquet obviously relate to the pulse-thrill, of which he has probably made observations more extensive and searching than any man. When in the future closer attention is bestowed upon this peculiarity of the pulse, we may perhaps discover unsuspected value in his descriptions. For the present it is clear that the spherules which he delineates are the eddies producing the thrill, and that their summit would convey to the finger the impression of a number of convex particles in motion. Fouquet's mistake was merely one of interpretation.

The expression "petits flots" constantly recurs in the individual accounts of cases, as in the following (*loc. cit.* p. 185):

> ". . . . L'élévation tombe et laisse sentir sous l'indice, à commencer dès le côté voisin du médius, une file de petits corps ronds ou de petits flots bien marqués qui se suivent rapidement, en paroissant s'allonger sous ce dernier doigt, et vont former un peu au-delà, un fourmillement grenu qui semble dilater l'artère, en cet endroit."

Had Fouquet been content with the notion of wavelets, his description of the pulse-thrill would have been strictly correct; but in spite of this partial misinterpretation, the objective genuineness of his sensations remains.

Lastly, it is in connection with this pulse, the most difficult to analyse and to depict, that Fouquet becomes dimly conscious of a *retrograde* process under the finger. The following statement is most explicit in this connection :

> "Dans cette extrêmité l'on sent une traînée de petits corps ronds ou de *petits flots* qui semblent aller se briser vers l'apophyse du rayon, en faisant, pour ainsi dire, *reculer la colonne du sang*, et formant, dans cet endroit, un fourmillement grenu."

CHAPTER IV.

CONCLUDING REMARKS ON FOUQUET AND HIS WORK.

So close an observer cannot fail to have been a good physician, and, of this, indications appear in the clinical histories appended to his work. As a thinker he does not reveal himself to us; there was probably more originality in the man than is allowed to transpire in his writings, where authority is used as a fulcrum to establish the correctness of his views with an incredulous profession. Conflict with the latter, and the striving after unanswerable proofs which the physiology of his day was incapable of giving, confined his attention to his one object of study, and caused him to accept without question erroneous doctrines, conformity with which was held to be the only test for the value of new ideas, and to cling the more strongly to teachings which his independent thought might otherwise have mistrusted.

The Theory of the Organic Pulses.

This faulty basis marred the clinical usefulness and the success of his discoveries. De Bordeu's theory of the organic pulses contained a greater proportion of truth than it is generally believed to possess. The influence of particular diseases on the pulse is undeniable, as for instance that of Bright's disease, that of enteric fever, etc., and their recognised connection with certain organs goes far to justify the theory. Unfortunately the latter was urged beyond the limits of general conclusions. The organic influence was erroneously thought to act directly on the pulse, whereas its action is on the blood or on the nervous system, and only through these on the pulse.

In the measure in which its applications were of a general kind the theory worked "true." In broad outline, the pulse varieties described as the Superior and the Inferior, the Pectoral, the Capital, the Intestinal, the Renal, and the Pulse of Diaphoresis, all correspond to types with which we are familiar. Definite pulse-peculiarities also accompany visceral hæmorrhage. Indeed, without renewed study, it would be rash to draw the limit at which the theory ceases to be applicable.

With this reservation, the organic theory, in the detailed application which was attempted by Fouquet, is wrong and utterly misleading.

It remains for us to explain how this fact is compatible with the correctness of the observations recorded and with the experience and skill of the observer.

The Factitious Nature of Some of the Pulse-Characters Described by Fouquet.

Quite unconsciously Fouquet was something more than a fine observer—he was a great virtuoso on the pulse. The pulse may be played on, and Fouquet acquired unrivalled proficiency in the art, without ever suspecting his self-deception.

The remarks on Pulse-thrill (see p. 376) give a practical illustration in point. Any one can, by sufficient application and by sufficiently varied tactile manœuvres, obtain a pulse-thrill in a proportion of subjects, which will yield no thrill with the ordinary methods. Any doubt would be cleared up by Fouquet's own words (*loc. cit.* p. 104):

> "Il convient maintenant d'observer que pour bien saisir le caractère du Pouls *uterin* suivant notre méthode, on doit, la plûpart du temps, pencher un peu en avant la rangée des doigts, une fois qu'ils sont placés sur l'artère, et presser de *l'index* un peu plus que des autres, en le rélevant de temps en temps ou suspendant la pression de ce doigt, sans néanmoins lui faire quitter l'artère ; en un mot, varier la pression des doigts, principalement de *l'index*, jusqu'à ce qu'on ait bien reconnu tout ce qui est essentiel au caractère qui vient d'être décrit."

By using four fingers, the range of the variations to be obtained by manipulations was much increased. Had Fouquet used one finger only, he would have avoided this fallacy. The peculiarities which his method enabled him not only to observe, but also to elicit, were doubtless more conspicuously, as well as more readily, yielded by certain pulses ; and his fine appreciation was thus enabled to make real distinctions as well as those which were unconsciously manufactured ; and again spontaneously objective features of the pulse (such as may be obvious to one finger) dovetailed with others purely artificial. Thus it is hard to say of any one of the types that it is false in all points. This obvious partial correctness must have helped to confirm him in a belief in his own results; and these probably seldom failed him, since he was generally able to produce by the touch the pulse character he was expecting to find.

Fouquet's Achievements.

In spite of these mistakes, Fouquet achieved a great work in vindicating for the touch a province which had been almost wholly neglected since Galen, and which was in this century to be exclusively claimed for the instrumental method; and he made good the title, by himself setting the first example of a systematic and searching tactile analysis. None have been found to follow it, and his ideas have slept in oblivion. Still after upwards of a century his work revives fresh and fruitful, fit to be taken up and completed by a generation of clinical students more able, more hopeful, and more appreciative.

We cannot more fitly conclude this imperfect survey than with a passage from Fouquet's own epilogue (*loc. cit.* p. 126):

> "Si on a vû un observateur se tromper réellement dans ses premiers essais, s'il se trompe encore quelquefois en cherchant à perfectionner une invention, il n'y a rien là qui ne puisse tourner au profit de ceux qui viendront après lui, qui se tromperont d'autant moins.* Une vérité est ordinairement payée de mille erreurs, et elle n'est pas chère a ce prix: mais il y aurait une injustice affreuse à grossir ses erreurs présentes de ses erreurs passées. Que si sa persévérance ne vous touche, du moins ne mérite-t-elle pas que vous le découragiés.
>
> "Pour ce qui me regarde, je ne prétends pas passer pour plus

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* "Si non errasset, fecerat ille minus." (Mart. Epigr.)

habile que je ne suis; j'avoue sincérement que je me suis mépris au Pouls et que je m'y méprends encore quelquefois (quoique plus rarement qu'on ne s'obstine à le publier), soit par mon imprudence, soit par des circonstances qui sont audessus de mes forces. Après un pareil aveu, nous nous flâtons que tout Lecteur impartial et éclairé rendra justice à la pureté de nos intentions en publiant cet ouvrage, et il doit peu nous importer ce qu'en penseront les autres."

PART VII.

EPITOME OF RESULTS AND FINAL CONCLUSIONS.

The results of this elementary study may be looked for in three directions :

I. In connection with the tactile method ;
II. In connection with the theory of the pulse ;
III. In connection with the practice of tactile sphygmology.

I. THE ANALYTICAL TACTILE METHOD.

The chief object of this work has been the vindication of the tactile exploration of the pulse as a means of scientific analysis. Methods are best judged by their fruits. The chief fruits of this method can only be developed from its application to the clinical study of disease, which has not been attempted in these pages. Thus the future alone can show whether the attempt has been successful. Meanwhile the observations which have served as a basis in the elaboration of the method, and as tests for its efficiency, although few in number, are not without weight. These may fairly be classed among the results, and included among those which we shall now briefly review.

II. THE RESULTS BEARING UPON THEORY OBTAINED BY TACTILE ANALYSIS.

We may conveniently divide the theoretical results into two groups: those immediately connected with the pulse-wave, and others having reference to the more distant relations of the pulse to the cardiac mechanisms. The connection between the two groups is really very close, since according to some authorities the shape of the pulse is explained by the mode of the heart's contraction, whilst others look to the pulse for information as to some of the intracardial events.

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CHAPTER I.

THE TACTILE METHOD AS ANALYZER OF THE PULSE-WAVE.

Data Supplied by the Tactile Method as to the Nature of the Pulse-Wave.

A Postulate.

BEFORE any of the conclusions which we have to submit can be put forward, the acceptance of the following postulate is a necessary preliminary : *The ictus felt by the finger is identical with the summit of the pulse-wave, as displayed in the sphygmogram.*

If this be granted, tactile analysis is capable of supplying most valuable data. Indeed the touch affords a simple answer to some of the pulse problems which von Kries and von Frey have laboriously worked out by instrumental methods. It opens up an unsuspected reserve of evidence, upon which these observers have not drawn, and which, even at this stage, may provide for their views that obvious demonstration which alone secures for new ideas a general recognition. Lastly, the interpretation of the sphygmogram is another work needing assistance such as this method can give.

Among the general features of the pulse, *size*, *strength*, *consistence* and *rate* have always been, by common consent, within the competence of the finger. Improvement of our previous knowledge on these points was the only need; and this, the tactile method has to a large extent supplied. *The nature of the pulse-wave, its relative time, and its direction* were new subjects for tactile study; it is chiefly in this direction that fresh ground has been broken.

The Direction of the Pulse-Wave.

Since Harvey's demonstration of the circulation the direction followed by the intra-arterial pulse-wave has been self-evident. That of the pulse-beat seems to have been regarded as hardly less obvious. As far as known to the writer, doubt has never been felt as to the relation existing between the ictus and the pulse-wave. At any rate modern literature contains no hint that the beat might be anything but a direct expression of the pulse-wave, strictly identical with it in time, and therefore centrifugal.

This conclusion appears to have been taken for granted by physiologists, since the question is not even raised by the numerous observers who have recorded their experimental estimates of the time-intervals corresponding to the progress of the wave from proximal to distant points. The most recent author, M. von Frey, makes no mention of the subject. Von Kries is also silent, and this is the more strange since he reproduces (*loc. cit.* p. 67) and analyses Hürthle's sphygmograms, in which the facts are displayed which raise the question.

The tracings, (Fig. 192, p. 477) copied from von Kries' book, were obtained by Hürthle from a proximal and from a distal point of the carotid respectively. They show that the summit of the wave is reached earlier at the periphery than at points nearer the heart. This is precisely what the tactile method has taught us (*cf.* p. 321) in the case of the radial artery.

This then is our first important contribution to the theory of the pulse-wave:

(1) *Although the progress of the pulse-wave is centrifugal, the progress of the pulse-beat or ictus is centripetal; the beat is felt earliest at the peripheral, and latest at the central end of arteries.*

As seen from the tracings, this can be demonstrated by the sphygmograph also. Our next point, however, lies beyond its scope. The instrument is unable to show us the direction of the waves which it registers: the finger does this with ease whenever the waves are perceptible to the touch. Again there is no selective power, in the sphygmograph, for certain waves to the exclusion of others; all are registered alike, without any possibility of distinction. This double disability is one of the gravest shortcomings of the sphygmograph, and is answerable for much delay in the advance of our knowledge of the pulse-wave.

The superiority of the finger as an instrument of analysis shines forth; and we are provided with two further results in confirmation of the first:

(2) *The pulse-wave and the pulse-beat are capable of being felt as distinct from each other; and*

(3) *Their opposite directions can be identified.*

The Relative Time of the Pulse.

The earlier time of the beat at the peripheral, instead of at the central end of arteries is, up to the present date, an exclusively tactile result, and much to the credit of the method. It is not supported, but directly opposed, by the accepted experimental data. Still it is a hard fact, and should be capable of an objective demonstration even more striking than that given on p. 323. Dr. G. A. Buckmaster, of St. George's Hospital, is kindly lending his skill and physiological experience to the graphic determination of the facts.

The conflict in results is more apparent than real. Donders' method by air conduction, and the electro-magnetic method, both register the transit of the *head of the pulse-wave*:—the finger is concerned with the *ictus* only. Comparison with our results is therefore only possible in the case of methods which have employed the finger as the receiving agent. E. H. Weber's original method was of that kind. He estimated the velocity of the pulse-wave at 7·92 to 9·24 metres per second.

Although most probably counting the moment of the pulse-beat, he did not succeed in timing its progress, nor has any physiologist, so far as known to the writer, hitherto timed it. His method, which was copied by Donders, Czermak, and others, consisted in observing the pulse at extreme points in the body, instead of at extreme points in any one arterial highway, and of calculating the velocity from observations taken on two arteries, instead of obtaining the result directly from a single one. E. H. Weber used a chronometer beating the third of a second, and felt the pulse of the External maxillary artery with one hand, and that of the Dorsalis pedis artery with the other; he found an interval of $\frac{1}{6}$ to $\frac{1}{7}$ of a second between them; but no appreciable difference could be made out between the pulses of the External maxillary and of the Axillary arteries.

Assuming that his guide was the pulse-beat it is equally remarkable that he should have failed to recognize the centripetal direction of the beat, and that, from the centripetal wave, he should have been able, without gross error, to determine the velocity of the centrifugal wave.

Instrumental registration was employed by later observers, Czermak using sphygmographs, and in other experiments the reflection of a ray of light on a glass surface set in motion by the artery; and Landois, electro magnets. All those observations, however, were made on two arteries belonging to different arterial districts, and this was also the case with Grunmach's experiments.

Alone Hürthle * confined himself to a single artery, the external carotid, taking tracings from its proximal extremity, and from the point of origin of the lingual artery. He seems to have concluded that the summit of the wave occurred earlier at the proximal extremity; but his tracings do not afford complete evidence on this point. (See Fig. 104, p. 226.)

The discrepancies in the estimates obtained with various methods by various observers, are in part due to true variations in the intra-arterial velocities, from causes (*cf.* p. 200) which have been pointed out by von Kries and others.

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* Pflüger's "Archiv," Bd. xlvii.

But with any method it must be difficult to ensure that in each experiment the earliest phase of the pulse-wave is registered. The inherent doubt as to whether the first arterial movement registered was also the earliest intra-arterial wave-movement, and the uncertainty as to the extent of the possible delay in each case, cannot but cause diffidence in connection with the great disparity in the figures of various observers, (*e.g.* E. H. Weber, 9·24 metres per sec.; Garrod, 9–10·8; Grashey, 8·5; Moens, 8·3, and with diminished pressure during Valsalva's experiment, 7·3) (Landois' Physiology).

Von Frey (*loc. cit.* p. 127) has reckoned out and tabulated the velocities (in the upper and the lower limb respectively) corresponding to the figures obtained by the several experimenters:

VELOCITIES OF THE PULSE-WAVE—IN METRES PER SECOND.

	In the upper limb.	In the lower limb.
Czermak	6·70	11·16
Landois	5·77	6·43
Grunmach	9· 0	11· 0
Keyt	7·37	6·83
Edgren	7·63	6·20
	7·32	6·59

The comparative evenness in velocity obtained in the two limbs by Landois, Keyt, and Edgren must raise a suspicion that such disparities as those found by Grunmach, and especially by Czermak, were due to some fundamental error in experiment; especially as they find the wave travelling faster in the lower extremity than in the upper.

This radical contradiction between authorities seems to have been accepted as a mystery beyond the pale of discussion. The clue to its explanation is probably contained in the following fact contributed by the tactile method:

(4) *Although the pulse-wave reaches the periphery latest, the pulse-beat occurs earliest at the periphery; and, within the same arterial conduction, earlier at any more distal than at any more proximal spot.*

An interesting corollary, which at the same time affords striking confirmation to the observation that the distal beat occurs earlier than the proximal, is also derived from the method:

(5) *The anastomotic beat at the wrist, although sometimes later, is most often earlier than the brachial beat.*

Passing over minor gains we learn the important fact that:

(6) *The touch can appreciate extremely small differences in time.*

And moreover:

(7) *The visual perception of the beat is markedly delayed as compared with the tactile perception.*

The Mode of Production of the Pulse-Wave.

The preceding statements concerning the time and direction of the pulse-beat have a far-reaching significance. If confirmed by experiment they pledge us to one of the theories of the pulse-wave; nay, they are in themselves a practical confirmation of the theoretical and experimental evidence accumulated in favour of the peripheral rebound theory, and which can be summed up as follows:

> Speaking of the first of the two predicrotic waves, von Kries (*loc. cit.* p. 95) says: "Dass gerade hier die rückläufige Welle zur Beobachtung kommt, und dass dieselbe gelegentlich die Form eines markierten Gipfels im Sphygmogramm annehmen kann. Unter diesen Umständen könnte man also sagen, dass gewisse Formen des ersten Zwischenschlages als Ausdruck der einmal reflectierten rückläufigen Welle anzusehen sind." He therefore regards the wave immediately adjoining the main summit as a wave of peripheral rebound, whilst the second predicrotic wave is, according to him, a descending wave of rebound.

Since the dicrotic wave is unquestionably also a reflected wave, the pulse-wave is essentially made up of reflected waves. Although this view was formed and formulated before the tactile method was thought of, still the latter has supplied the practical confirmation; and the following statement may be reckoned as one of its fruits:

(8) *The configuration of the pulse-tracing arises from the conjunction with the systolic wave of a series of rebound-waves, the first of which is reflected from the periphery.*

So strongly does tactile analysis support this view, that throughout these pages our facts have been recorded in terms of the *peripheral theory* of the pulse-wave. Our adhesion to this theory is therefore a foregone conclusion.

CHAPTER II.

THE TACTILE METHOD IN CONNECTION WITH THE HEART AND WITH BLOOD-PRESSURE.

Data Supplied by the Tactile Method as to the Mechanism of the Cardiac Systole.

THE acceptance of the peripheral theory practically excludes the central theory. Tactile analysis of the pulse provides us, however, with something more than merely negative arguments. Any cardiac events capable of arterial transmission must keep accurate step with the heart-wave. If the ictus be entitled to the name of percussion-wave (in the sense of systolic percussion) or to that of papillary wave, it must satisfy this test throughout the arterial system. The foregoing observations would show that it does not. Far from running hand-in-hand with the systolic wave, the ictus has been found to take an opposite course. The retrograde march of the ictus would therefore enable us to state in general terms that:

(9) *The percussion-wave is not directly produced by the cardiac systole, or by the contraction of the papillary muscles;* and that

(10) *Conclusions based upon the configuration of the early part of the sphygmogram, as to the mode of the cardiac contraction, lack secure foundation.*

If this be true in the case of the ictus, the probability is great that it is also true of the predicrotic wave. But the tactile method not being competent to judge of the latter, we are restricted to the *a fortiori* argument. The absence of this wave in some pulses and its accentuation in others are satisfactorily explained in the theory of peripheral rebound, less easily in the central theory.

Other Results bearing on the Theory of the Pulse-Wave.

Dicrotism.

The contributions of the tactile method to this subject have hitherto been indirect only, yet important. Suggestions have been made which are based upon, and derive their probability from, our better acquaintance with other arterial rebounds. It would be premature, however, to put forward as proved these and other points of theory which may eventually be seen to have owed their proof to the tactile method.

The Changes in the Pulse due to Posture.

In this wide class one instance only has been singled out for study by physiologists, and to this we have confined our attention. The pulse-changes induced in the radial artery by raising the arm, had given rise to many theories, until the whole subject was a hopeless tangle. For this, the tactile method has the credit of having substituted a few plain facts :

(11) *The changes in question are not due to gravitation ;*

(12) *They are equally obtainable, by the same movements, in an absolutely horizontal, instead of a vertical, position, of the whole body and of the limb ;*

(13) *They are not special to the movement and posture in question ; but may be also obtained at will with the arm dependent, and in other positions ;*

(14) *They are induced by constriction of the artery ; their features are those of the pulse of stenosis.*

(15) *Arterial constriction is partly due to pressure of the contracting muscles, partly as an indirect result, to the tension of fibrous structures and of tendons.*

(16) *Constriction sufficient to obliterate the pulse may be brought about by raising the arm in a special way, or by definite contraction of the muscles without any elevation of the arm.*

(17) *The changes usually described have not the value of a definite and independent arterial condition ; they are merely a stage on the way to arterial obliteration. The results of individual experiments are therefore essentially variable.*

It is needless to point out that these facts facilitate a correct interpretation of the sphygmogram, and that they throw light upon the subject of pulse-pressure.

Pulse-Pressure.

Important conclusions are contained in the facts stated below:

(18) *Pulse-pressure in one limb is not always a safe guide to the general pulse-pressure of the body, nor even to that of the other limb.*

(19) *The pulse-pressure, wheresoever determined, may be purely local, and therefore due to local causes.*

These results cannot be claimed as exclusively due to the tactile method; the demonstration only is new.

Its Registration.

Again, of late, the failure of the sphygmogram as a record of pressure has been more widely recognised, but the tactile method has brought into great prominence the fact that:

(20) *The sphygmograph is incapable of indicating the direction of the waves of pressure which it registers.*

Of this the demonstration has been given in a very striking way by our observations on the proximal and distal ictus, and on the anastomotic pulse: events of which the sphymograph entirely fails to notice the direction.

(21) *The construction of the sphygmograph lays it specially open to faulty registration of the degree of pulse-pressure.*

Marey (*loc. cit.* p. 286), in selecting the shape and size of the button of the sphygmograph, had in view to cover as much of the artery as possible, and thus to obtain a greater rise of the lever, and the registra-

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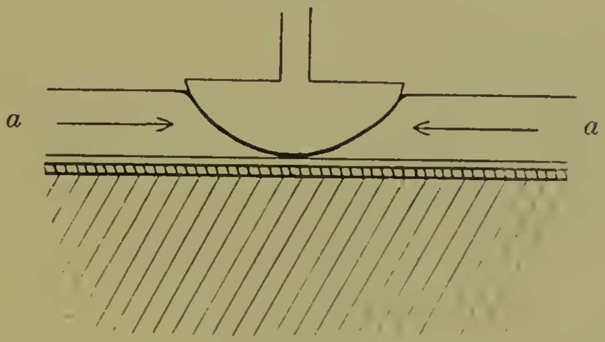
tion of vibrations otherwise scarcely appreciable to the finger. This is not an unmixed gain, so long as the derivation and direction of the vibrations are not indicated.

It will be noticed that the shape and curvature of the button are precisely such as would give to the proximal or the distal ictus a special advantage in registration over the more central pulse. And again, as we have learnt from palpation, we shall be dealing with a different kind of pulse at each variation of extra-arterial pressure.

FIG. 189.



A. Diagram of an artery resting on bone; showing the way in which the waves take effect on the button, in spite of the pressure used.

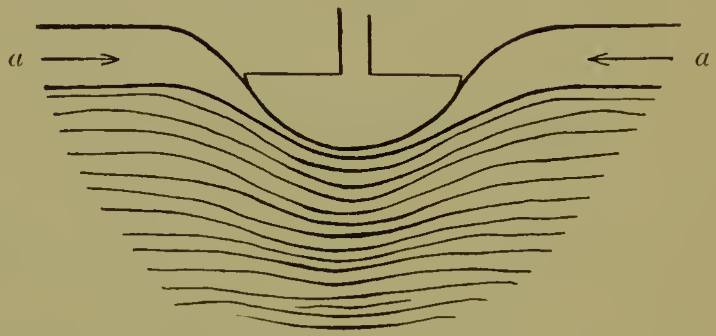
If it be attempted to determine the intra-arterial pressure by loading the lever progressively to the point of obliteration, the pressure of the button would tend to obliterate only the central portion of the pulse; the sides of the button would remain subject to the lateral influence of the ictus. Even though it may not be lifted by this influence, the lever may be sufficiently disturbed to record oscillations.

The diagrams represent the two cases which may occur.

If the artery rests on bone as in (A), although obliteration may be effected in a line with the vertical axis of the button, the lateral portions (*a*) and (*a*) will not be obliterated; and the lever may move, though hardly any blood passes. An accurate record of the pressure is not obtained.

If the ivory button should not be resisted by bone, but by soft parts, though complete occlusion may be ultimately achieved, it will be impossible to tell how much of the pressure employed went to neutralise the intra-arterial pressure, and how much was used in condensing the soft parts and depressing the artery.

FIG. 190.



B. Diagram of an artery supported by soft parts. The pressure from the button is in large part expended upon the latter.

Its Nature.

From tactile observation alone, showing the ascending direction of the ictus, it was possible to have traced the intra-arterial pressure to one of its sources. This, however, had already been achieved, on much more difficult lines of research, by von Kries, von

Frey, and others. The tactile method may, at any rate, be said to have furnished the demonstration of the view that:

(22) *Some part of the intra-arterial pressure is due to the summation of the peripheral rebounds.*

The tactile method has also been the means of supplying confirmatory evidence that:

(23) *The duration of the pressure, and therefore of the arterial tension, also partly depends on rebounds.*

The Systolic Pulse-Pressure.

Tactile observations, combined with a study of sphygmographic tracings, have suggested that:

(24) *It is desirable to emphasize the distinction between systolic pulse-pressure and mean pulse-pressure.*

The combination of a high systolic pressure at the onset, with a low pressure during the remainder of the wave, is the rule in the fully "dicrotic" pulse, and in aortic regurgitation. Pressure, in the case of the dicrotic pulse, is absorbed in the capillary district, rather than deficient at the heart (allowance being made for the smallness of the ventricular output). In aortic reflux, in spite of a large output, pressure fails centrally, after the systole, but it is also lost peripherally into the capillary system; a double depression which causes this to be the most extreme instance of an abrupt fall of the systolic pressure.

Pulse-Pressure in Relation to the Periphery.

Some idea of the extent to which the arterioles (as originally shown by Sir George Johnson) and the capillaries are capable of disposing of the intra-arterial pressure, may be gained by closing the way to the capillaries. It has been shown that, by pressing the finger firmly on the pulse, a proximal ictus is developed:

(25) *The relative strength of this ictus will be (cæteris paribus) greater, as compared with the previous strength of the pulse, according to the amount of pressure previously absorbed by the capillaries.*

To Dr. George Oliver belongs the credit of having based on this variation in the size * of the proximal ictus an important method of investigation, from which much future result may be expected, and to which we already owe valuable contributions to the study of the variations in arterial pressure induced by attitude, temperature, etc.

Other Results more strictly Clinical.

The necessity for a preliminary review of recent theories, the elaboration of the details of the tactile method, and its still immature state have hitherto deprived the writer of all opportunity of applying it to its ultimate object, the study of disease. Until this has been done practical contributions bearing upon clinical work must be few. To this class may be reckoned, in addition to the more useful results, the observations which have been made on the Radial Thrill and on the Radial Anastomotic Pulse.

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* In connection with the results of blocking the artery, see pp. 158, 163. (vaso-paralysis—proximal ictus, etc.)

The Radial Thrill.

Pulse-thrill has been shown to exist in some pulses almost independently of the observer. At least, it may be elicited by the mere application of the finger at definite points. These cases are exceptional.

(26) *As a rule the radial pulse-thrill is the result of some special manipulation; it is an artificial product.*

The most familiar pulse-thrills, such as those of the carotid, of the brachial, and of the popliteal arteries are due to accidental pressure occasioned by the attitudes of the body or of the limbs.

The Radial Anastomotic Pulse.

Hitherto, the study of the anastomotic pulse belongs exclusively to the tactile method. We have found that:

(27) *An anastomotic pulse is more commonly perceptible in adults than in children, and can be recognised in a majority of the former.*

(28) *When allowed to ascend the distal end of the radial artery, by an artificial exclusion of the direct pulse from the latter, the anastomotic pulse presents all the attributes of the ordinary descending radial pulse.*

(29) *The ascending pulse acquires, however, in its passage through the narrow channels of anastomosis a stenotic character.*

(30) *The distal rebound (from the hand) instead of being in conflict, is identical in direction, with the pulse-wave in its radial course.*

(31) *In spite of its longer journey, and of all retarding influences, the anastomotic pulse commonly gives to the obliterating finger an earlier stroke than that communicated to the proximal side of the same finger by the ordinary descending pulse.*

(32) *In other cases the time of the two events is reversed; in a few only it is identical.*

(33) *When the direct radial pulse is not stopped by an artificial block, the anastomotic reflux is suppressed by the stronger descending current; but the anastomotic wave probably ascends the radial artery. The effect of the suppressed current would be to raise the intra-arterial mean pressure; and that of the wave, to increase the intra-arterial systolic pressure.*

CHAPTER III.

THE PRACTICE OF TACTILE SPHYGMOLOGY.

THE PRACTICAL METHODS.

1. **Feeling the Pulse.**

OUR conclusions relating to method are simple and briefly stated; their importance lies in the future work they are to govern. The sum of the lessons conveyed in this study is given in two words: *Analysis—Definition.* Our great object is to analyse the pulse; and our first need towards that end, definiteness and, therefore, singleness of impressions.

Hence our great rule:

(34) *Never use more than one finger to the pulse except for special objects.*

The accident that there should be, at this date, something novel to record in pulse-sensations seems to be entirely due to the neglect of this rule; and to the general adoption of the opposite rule, which effectually prevented Fouquet, and has effectually prevented other observers, from perceiving important tactile features of the pulse.

*

The details of the method will be found under the corresponding headings.

2. Determining the Presence or Absence of the Anastomotic Pulse.

(35) *To recognise the presence of an anastomotic pulse the single finger usually suffices. To ascertain conclusively its absence two fingers are needed, and it is safest to use both hands.*

This rule, virtually contained in the earlier statements by Ozanam, Douglas Powell, and others, needs to be stated here in connection with the description of the following operation.

3. Estimating Pulse-Pressure or Arterial-Tension.

This may be done by obliterating the pulse, that is, closing the artery by pressure. In carrying this out according to the old method, the possibility of an anastomotic pulsation being mistaken for the direct pulse, and of the pressure being thus overestimated, had led to two fingers and even three being used. This, as it was thought, necessary precaution is a rational explanation for the survival, up to the present day, of the faulty method of multiple fingering, which formerly rested mainly on tradition and on a belief that more could be felt of the pulse in proportion to the number of the fingers used.

In view of the importance of using one finger only for palpation, any method of satisfactorily performing with a single finger the universally needed test for pulse-pressure would be a great gain. This is supplied by the tactile method. The new process for roughly estimating pulse-pressure is based on the peculiarities of the three kinds of ictus; we are, however, more specially concerned with the proximal, and with the distal ictus only.

The appearance of the proximal ictus, that is, the perception of a beat on the heart-side of the finger, is a reliable proof that the progress of the pulse-wave has been stopped; and this again implies that the way through the artery has been so much reduced as no longer to transmit a wave sufficient to yield a perceptible distal rebound. For all practical purposes this means that the intra-arterial pressure has been overcome by the extra-arterial pressure. In the majority of subjects a moderate pressure of the finger will dispose of the distal ictus, and at the same moment the proximal ictus will be felt, the amplitude of which will afford collateral evidence of the successful obliteration of the artery. In a smaller number, considerable pressure will be needed to suppress the distal ictus; and a doubt may arise as to its possibly anastomotic character. This doubt is usually set aside by the observation that the full-sized proximal ictus has meanwhile come into play.

A single finger will thus suffice to decide both the question as to tension, and also that as to the existence of any markedly anastomotic pulsation. Nevertheless, instances may occur, but their number will be very small, in which the observer will not feel satisfied until he has applied the classical test for the presence of the anastomotic wave. If it should be absent, or hardly perceptible, the case falls into the usual category, and may be dealt with confidently with one finger. Thus the rule for estimating arterial tension may be stated as follows:

(36) *Apply the index finger lightly. Having found the distal ictus, gradually increase the pressure until the distal ictus vanishes; and at that moment watch for the ictus at the proximal side of the finger. The amount of pressure used will be a measure of the tension of the pulse.*

The chief recommendations of this method are its simplicity and its definiteness. It is purely comparative, and aims merely at an approximative result; but it is so readily performed that a succession of cases can be rapidly compared, and a standard quickly arrived at. With the sphygmometer it does not pretend to compete; but it is next best to an instrumental method in precision, whilst open to none of the attendant objections. With its aid a practical estimate is gained of the tension of the pulse, without any effort; for the operation, capable of repetition many times in a minute, consists simply in a systematic variation of the pressure of the finger; whilst the same position of the finger enables us to judge of almost all the qualities of the pulse.

A slight qualification is needed in the previous statements. A short interval does occur between the relatively sudden disappearance of the distal ictus and the full strength of the proximal ictus, and this is occupied by the *intermediate ictus.* In the *soft* pulse the first event needs slight pressure and time, the second event a very slight addition of both; the intermediate ictus is fugitive and almost impalpable.

But the *tense* artery, which has long and strongly resisted compression, will need an appreciable increment of pressure to obliterate it completely as far as the proximal border of the finger. Until this is done the intermediate ictus will continue to be felt, and the proximal ictus will not acquire its full strength. From these observations we derive a supplementary rule:

(37) *Whenever, during gradual application of pressure, a marked intermediate ictus is obtained, we have further evidence of sustained pulse-pressure. The full extent of the latter is to be measured by the disappearance of the intermediate ictus, which coincides with the moment of complete evolution of the proximal ictus.*

The duration of the intermediate ictus thus acts as a confirmatory test for the correctness of the result obtained under the preceding rule.

Palpation with the Thumb; and Palpation with Several Fingers.

The general rule which has been laid down should not be taken to imply that no advantage is to be obtained by examining the pulse over a greater length than can be covered by the tip of one finger. On the contrary, this procedure will be found a most useful adjunct to the ordinary method, in the analytical study of the pulse, as soon as the elements of tactile sphygmology shall have been thoroughly grasped. It enables us to follow the waves in *their progress*; whereas the single finger takes cognisance of *their transit* only. There are two ways in which this can be done: by applying the length of the thumb to the radial artery; or by placing on it the tip of two or three fingers. With either of these methods many of the peculiarities which have been described may be verified.

(1) The thumb is more often applied with its base at the wrist and its extremity towards the elbow. This position will enable it to feel the proximal ictus with great nicety. The same is true of the index finger laid, in the same direction, flat over the length of the artery. The distal ictus will, however, not be obtainable. If the thumb, or the finger, be placed in the opposite direction, with the tip at the base of the styloid process, the distal ictus will be perceived excellently; and the proximal ictus can also be felt by the base of the phalanx where this rises from its contact with the arm. Indeed, there is no better method for a fine tactile appreciation of the ictus; the latter striking a very sensitive surface, a little in advance of the end of the bony phalanx by which pressure is exerted. The same mode of palpation is specially adapted for the study of the intermediate ictus, which, in the ordinary method, is a little difficult to secure. The travelling events, however, are those which it most helps us to perceive—viz., the systolic pulse-wave and the wave of the ictus, in their opposite propagation.

(2) The second method, which uses the tips of several fingers in loose order, supplies us with a number of tactile combinations, and with an almost inexhaustible variety of observations. The various kinds of ictus, the anastomotic pulse, the pulse-thrill, are all within its competence. The greatest service which it renders us is in the appreciation of the fundamental fact of sphygmology, which we must once more record :

(38) *The ictus travels, in all arteries accessible to the touch, in the shape of a wave from the periphery towards the heart; its direction being opposed to that of the systolic pulse-wave.*

If four fingers be applied to the radial artery this retrograde march becomes very obvious, especially if they be slightly spaced from each other; each event is then perceived eight times in its transit, as it reaches and as it leaves each of the fingers in succession. The perceptions may be too rapid to be individualised, but they are consolidated by their repetition into a conclusion which leaves no doubt whatever in the mind. Indeed, since even with one finger the direction of the waves can be made out, how much easier must this be when a longer section of their journey is observed. There is in the feeling of the wave rolling under finger after finger a completeness of sensory evidence which nothing can equal; but much experience in the modulation of finger-pressure is essential, failing which the opposite waves might both be allowed to come into play simultaneously; or, unconsciously, the pressure corresponding to one of them might develop into that calling forth the other wave. Rather less risk, in this respect, attaches to the alternative method of using only the two extreme fingers in the row, namely, one for observing the moment of entrance, the other for observing the moment of disappearance of the wave. And it is to be noted that with the preceding arrangement also, all tactile judgments are largely based upon the perception of the interval between these two extreme moments of time.

The Methods for Observing the Priority between Two Pulse-Events without Instrumental Aid.

The objection to sphygmographic time-determinations is that we have no means of identifying some of the events which are being automatically timed. The pressure made, and the results of pressure registered by the button of the instrument lie outside our cognisance. To time whilst we feel is more satisfactory, so long as our timing is sufficiently accurate. In carrying out this indication, the finger arrangement in question assists us greatly. The ring finger or the little finger, and the thumb or the index, are placed respectively at the two distant points of observation, and two moments of time only are kept in mind, that of the occurrence of the sensation under one finger, and that of its cessation under the other.

The correct perception of intervals of time, so brief as to strike us at first as synchronous, is rendered possible by a simple method which deserves to be reckoned among the practical gains from tactile sphygmology.

(39) *If two tactile perceptions be almost synchronous, so as to partly overlap, a distinction in time may be made between them, by concentrating the attention in turns upon each of them, say first upon (B). If (B) should not possess priority, then the other perception will be completely extinguished; a single sensation, that at (B), will be felt. If the attention be now concentrated on (A), this, being the earlier*

of the two sensations, will of course be felt; but (B) will assert itself also, because, after (A) has ceased, it will hold the field alone.

(40) With the help of these two devices we can now approach our last and most difficult experiment, thus far, our highest achievement in tactile analysis.

A FINAL EXPERIMENT.

The Time of the Ictus, and of the Wave, Studied in the Carotid.

Although not a very convenient pulse to feel, the carotid has the advantage of a very large wave and of an unmistakable ictus.

Experiment XLV.

If the finger of one hand be placed at the origin of the external carotid, and a finger of the other hand over the vessel at the upper level of the larynx, the following succession of events may be recognised :

(1) On deep pressure the rush of the wave is readily traced in a centrifugal direction, and the distal finger *Df* receives the later impact.

(2) If the pressure be now reduced as much as this can be done without losing touch of the pulse, the beat or ictus will be felt instead of the wave ; and the order in which it will strike the fingers is exactly the reverse of what it had been for the wave. In this case the proximal finger, *Cf*, is perceptibly the last to receive the stroke.

(3) Any observer will probably succeed in tracing the tactile distinction between the two objects, and the contradiction in their time. The third observation is much more difficult. It aims at *feeling the ictus in the wave.* It must therefore be made with the stronger pressure of the finger. The wave is felt as in the first instance; but the attention must be entirely withdrawn from its onset and progress, and intently bent upon its finish. The apparently abrupt cessation of the wave corresponds to the ictus, and will be felt by *Df* before being felt by *Cf.*

FIG. 191.

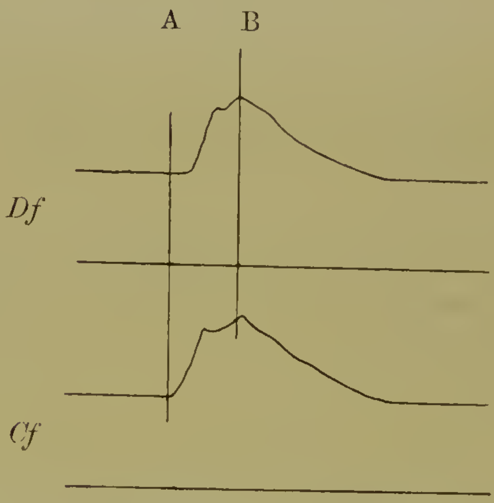


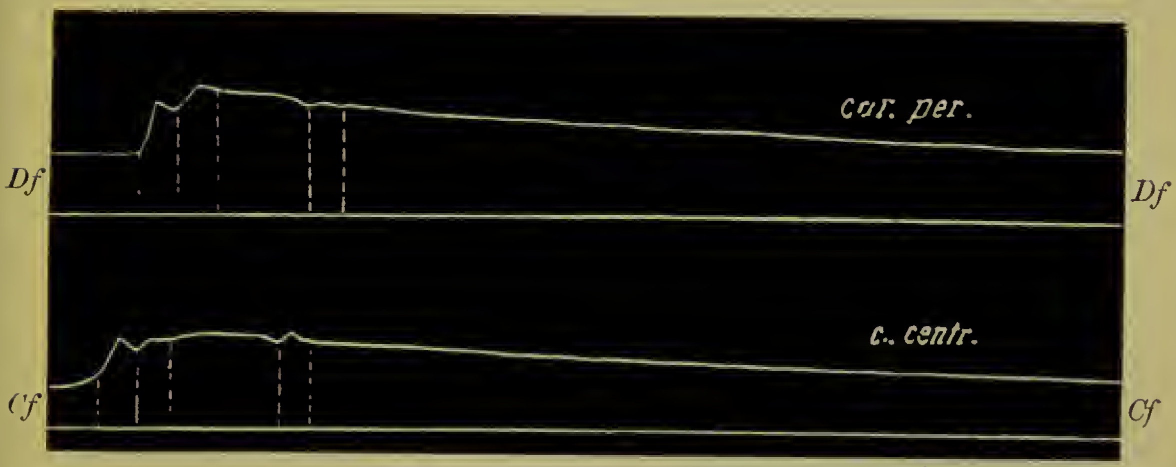
Diagram constructed from the tactile impressions of two fingers placed on the carotid artery, *Cf* near its origin, and *Df* near its bifurcation; showing disparity both in the duration of the wave and in the time of the ictus.

In this way the touch is able, in the case of the carotid pulse, to analyse so clearly the first part of the wave, that a diagram could be drawn by the observer of the relative time of the events, showing for each finger a rise and a subsequent summit, the rise beginning at a later moment, and the summit occurring at an earlier moment for *Df* than for *Cf*;

in other words, the curve for *Df* will be of smaller width, especially at its upper part, than the curve for *Cf*.

This diagrammatic representation of tactile events is the nearest approach we have arrived at, to an imitation of the tracings of the instrumental method; and it would be interesting to be able to compare it with a sphygmographic tracing in this particular case.

Fig. 192.



Unfortunately we know of only one set of sphygmograms taken simultaneously at different spots of the carotid, those of Hürthle (Fig. 192); and these are not explicit on the point at issue. Nevertheless it may be observed that the wave (reckoned from its foot to the later summit) is broader at *Cf* than at *Df*, and that the later summit for *Df* suffers decidedly less relative delay than the onset of the wave.

The carotid artery has been selected for this final experiment because in the radial pulse, owing to the small calibre and the remoteness of the artery, the first part of the wave is much narrower, and its events less tangible and less easy to analyse.

CONCLUDING REMARKS ON THE FUTURE OF TACTILE SPHYGMOLOGY.

Our task is in great part achieved, since we have secured recognition for the large share which should belong to the touch in clinical sphygmology, and established a few fundamental facts in such a way that we can await without anxiety the verdict of instrumental verification, when this can be obtained—for it would be rash to assume that existing instruments are able to deal with the more delicate tactile experiments claiming registration.

Whilst in progress the study has grown beyond expectation, and already exceeds the lines of this elementary sketch. Limits are not easily assigned to its future development. *Physiology* will find in tactile analysis many a suggestive problem. It is needless to enumerate the multiple lines of research opened up in connection with the theory of the pulse. Any one of the questions raised in these pages might become the starting-point for systematic investigations, the end of which cannot be even guessed, and which might call into existence novel instrumental methods. Indeed, as we write, this has already been fulfilled in one striking instance. Dr.

George Oliver's investigation, so fruitful and yet only begun, is practically based on one of the phenomena of tactile sphygmology, important in itself, as they all must be, but not claiming a very prominent position in connection with the theory of the natural pulse. This is probably but a foretaste of still richer harvests which the major issues might yield to patient investigation. The ictus, pure and simple, needs to be studied as to its time and direction, as to its velocity and duration and other characters, under varying physiological circumstances; and in its many-sided relations to the cardiac, capillary, and venous influences. The forms of ictus which are termed artificial, because modified by the pressure of the finger, will supply additional series of inquiry.

Again, the anastomotic events and the pulse-thrill are studies hitherto barely outlined.

In addition to inquiries such as these, which may be classed as novel, the old stock of unanswered questions remains, calling for renewed attempts at solution.

Beyond all this lies the vast and practically inexhaustible field of *pathology*, a soil left virgin still at the close of this inquiry.

Looking, then, towards the future, we no longer fear a continuance of the neglect and stagnation which have prevailed in the past. Neither the material nor the means need fail us in the progressive cultivation of clinical sphygmology. An opposite danger might be thought to threaten, that of too wide an expansion and too minute a detail. This is an evil which carries its own cure. Distinct and even divergent as may be, at their origin, the paths of research, we see them rapidly converge and ultimately join. This assured concurrence of all isolated efforts towards a final unity in results should encourage individual observation. Investigation cannot be too much varied, nor can the workers be too many.

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